INDUSTRY AND RESEARCH

THE FULL REPORT OF A TWO-DAY CONFERENCE

ARRANGED BY

THE FEDERATION OF BRITISH INDUSTRIES

AND HELD AT

THE KINGSWAY HALL, LONDON, W.C.2

MARCH 27th AND 28th, 1946

LONDON

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PREFACE

The two-day Conference on Industry and Research convened by the Federation of British Industries, at Kingsway Hall, on 27th and 28th March, 1946, was national in character, being attended by Ministers and ex-Ministers of the Crown who were or had been responsible for departments of State concerned with research, 1,400 delegates including many of our leading scientists and representatives of industrial firms, trade associations, scientific laboratories, research associations and the Department of Scientific and Industrial Research. It was a pleasure to welcome representatives from South Africa, Australia, Canada, New Zealand, United States of America, Belgium, Czechoslovakia, France, Holland, Poland, Russia and Sweden.

The subject of the Conference was the dependence of progressive industry on research and the application of science in promoting industrial efficiency and competitive power in world markets, with full employment and a higher standard of living.

This book is a record of the proceedings, containing the full text of the addresses, speeches and papers which were delivered; also a summary of the discussion at each of the last three sessions, as approved by the various speakers.

The book provides a comprehensive survey of a wide range of experience of a number of leading authorities on the organisation, direction and application of scientific research in industry. It is hoped that it will provide inspiration and some measure of guidance to those responsible for the direction of industry, as well as to a wider public.

Before the war industry and science may have held somewhat aloof. The Conference demonstrated conclusively that the close collaboration between the two is thoroughly understood, and that on their effective alliance largely rests the reconstruction of our economic life. It now remains for all of us in industry to translate that awareness into achievement.

On behalf of the members of the Federation of British Industries in particular, and of the representatives of Industry generally, I should like to place on record our appreciation of the work of the Industrial

Research Committee of the Federation under the vigorous chairmanship of Sir William Larke in promoting and developing interest throughout Industry in the application of scientific research, and particularly in organising this first great national conference on Industry and Research.

CLIVE BAILLIEU, K.B.E., C.M.G.,
President of the F.B.I.

The Conference was arranged by the F.B.I. Industrial Research Committee, the function of which is "to stimulate national interest in research for industry and foster it in all appropriate ways."

The following are the members of the Committee:

Sir William J. Larke, K.B.E., D.Sc. (Chairman).
Dr. S. B. Bagley.
Sir Peter F. Bennett, O.B.E., M.P.
Dr. W. T. K. Braunholtz, M.A., F.R.I.C.
Mr. O. F. Brown, M.A.
Dr. P. Dunsheath, C.B.E., M.A., D.Sc.
Mr. T. A. Fairclough.
Dr. W. H. Glover, M.A., F.R.I.C.
Sir William Griffiths, F.R.I.C., F.Inst.P.
Mr. A. L. Hetherington, C.B.E.
Mr. F. G. W. King, F.I.R.I., M.I.A.E.
The Rt. Hon. Lord Melchett.
Mr. R. O'F. Oakley, O.B.E.
Sir Clifford C. Paterson, O.B.E., D.Sc., F.R.S.
Sir Robert Pickard, D.Sc., F.R.S., F.R.I.C.
Mr. R. K. Sanders, M.A.
Dr. R. E. Slade, M.C.
Sir Frank Smith, G.C.B., G.B.E., D.Sc., F.R.S.
Mr. S. K. Thornley.
Dr. B. J. A. Bard (Secretary to the Committee and Head of the Industrial Research Secretariat).

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A MESSAGE FROM THE PRIME MINISTER TO THE CONFERENCE

The following is the text of a letter addressed by The Rt. Hon. C. R. Attlee to Sir Clive Baillieu, President of the F.B.I.

I send you my best wishes for the success of the important Conference on Industry and Research organised by the Federation of British Industries.

Now as never before we want the greatest possible production of capital and consumption goods of all kinds. We must therefore improve the output and efficiency of established industries and found and build up new industries. Thus we shall be able to increase our production of goods both for the home market and for export, and attain greater prosperity and the increased social security at which we all aim.

In all this scientific research must play a vital part. His Majesty's Government therefore welcome the initiative of the Federation of British Industries in holding this Conference at which will be considered in particular the application of science to industry; the relationship between research and industrial production and expansion; and the practical means by which research can assist industry and promote industrial efficiency, exports, full employment and a higher standard of living.

SESSION I

SCIENCE, INDUSTRY AND THE COMMUNITY

Address by the Chairman

SIR CLIVE BAILLIEU, K.B.E., C.M.G.,

President of the F.B.I.

I am sure that you will agree it is not necessary for me to justify the holding of this conference, which has been called under the auspices of industry. A few words, however, as to its genesis, may be appropriate.

The Federation has had under constant review the contribution which scientific research and the scientific method can make to the expansion of our industrial effort and the economic recovery of the country, following a long and exhausting war, which called for unprecedented efforts from industry, and the rest of the country.

A report on Industry and Research was made by a Committee of the Federation in October, 1943. This Committee was subsequently appointed a Standing Committee of the Federation, with its own secretariat, to work out a procedure by which the Federation could promote the interests of industry in relation to research and its applications, and could foster and encourage research in industry in all appropriate ways.

The Federation feels that this can best be done by encouraging industry to seek out the results of scientific research and to translate these results speedily into practice. Only those countries which have the brains and resources, the ability and the will to apply the latest results of science vigorously and continuously for the expansion of old industries and the creation of new ones, as well as to the improvement of productive practice and efficiency generally, will hold their own under the stress of post-war international competition. Only in this manner shall we be able to increase the production of wealth without which it will not be possible to maintain, let alone improve, the standard of living in this country.

It has recently been stated that there are approximately twenty million people gainfully employed in this country. Of these about one

million two hundred thousand must remain for an indefinite period in the forces of the Crown and a substantial number, estimated to be of the order of five hundred thousand, will continue to be engaged on the production of munitions and supplies for the Armed Forces.

Although by the end of 1946 the number available for industrial production for civilian and export purposes is likely to reach the 1939 level, the task imposed on them is much greater since real exports must be increased by at least seventy-five per cent. in volume. We must make good therefore not only the accrued maintenance of six years of war in our industrial and domestic equipment, but also the devastation it has caused.

It therefore follows that, if we are to restore our standard of living to pre-war levels, Industry must make a productive effort substantially greater than in 1938, but with approximately the same man-power. How can this be achieved ? Only by seeking out and achieving a broad measure of co-operation between all elements, Government, Employers and Operatives, and by the most efficient use of scientific research in its wider sense and throughout the widest field.

We are fortunate that we have maintained a foremost position in the field of scientific discovery and research. Whilst this provides us with the fundamental equipment necessary for the efficient conduct of our industry, we will only maintain our position in the world if we proceed to convert the results of scientific discovery and research into effective production. We must therefore examine together, as Industrialists on the one hand and Scientific and Research workers on the other, the possibility of promoting still closer collaboration between these two factors on which our industrial recovery so largely depends. We must aim at increasing the efficiency of our existing productive methods and the output per unit of man-power. Upon this will depend our industrial recovery and also the creation of those new materials and the development of those new industries which are essential to enable us to retain our position as a great trading and commercial nation.

The Federation, therefore, as the representative organization of British productive industry has convened this conference in the hope that it will provide a forum and a means of mutual consultation for the mutual enlightenment of two of the essential instruments of industrial progress, Science and Management. We must aim at creating in character, although it may not be possible to do so in degree, a new Industrial Revolution in this country. We must contrive in the years ahead to reproduce the team work, the close identity of purpose and action between Science and Management which was the

outstanding feature of our War effort. Our National slogan must no longer simply be

"Britain *delivers* the goods,"

but also

"Britain *creates* the goods."

The British manufacturer of the future will not be content with supplying his customers with high quality examples of the traditional articles of commerce at a reasonable price; he will welcome the opportunity to create new ones—specific materials for specific objects with individual properties to meet definite needs. By this means British products will be raised to constantly higher levels of utility, quality and value.

I therefore welcome all of you from industrial concerns, large and small, trade associations, scientific laboratories and research associations, who have responded so enthusiastically to our invitation to participate in this Conference.

On behalf of Industry I thank those distinguished Ministers and statesmen who have lent their authority and their support to this Conference by their presence and participation in our deliberations. We are deeply indebted to those leaders in the industrial and scientific world who have undertaken to address the Conference on theses which they have prepared for circulation beforehand and who have placed their knowledge and experience so generously at the disposal of us all.

SESSION I

SCIENCE, INDUSTRY AND THE COMMUNITY

Opening Address by

Sir Robert Robinson,

President of the Royal Society.

I am deeply sensible of the honour which the Federation of British Industries has conferred, in asking me, as President of the Royal Society, to open the proceedings of this Conference. Having served under the Chairman of the Federation's Research Committee, Sir William Larke, at the Ministry of Supply, and followed him in the Advisory Council of the D.S.I.R. and its Industrial Grants Committee, I have good reason to know his enthusiasm for progress and his flair for the translation of ideas into practical measures. An outstanding example will, I believe, be recognised in the conception and organisation of this symposium on Industry and Research.

Taking note of the restricted field implied by the literal interpretation of that title, I would nevertheless ask for your indulgence to allow me to mention that an improvement in the applications of science and technology to industry implies two things. First, the more effective utilisation of what is already known, and second, the acquirement of new knowledge by research, and its development and exploitation. Design and invention occupy an intermediate position and are even more important in many industries.

In the course of a visit to the West Indies in 1944, Professor Simonson and I saw many opportunities for applied research, but were still more struck by the needs for a higher standard of primary and technical education and for better scientific communications. That implies more resident scientists and technologists, closely associated with the industries, and vastly better facilities for the interchange of ideas with their opposite numbers in other parts of the Commonwealth.

In this country too, we urgently need more Universities with Scientific Departments and many more Technical Colleges so that science and technology may permeate every section of all industries and not merely filter from their research laboratories. I do not

believe that super-saturation is possible and, at any rate, we are far enough from such a condition at the present time. Naturally the first priority is for the improvement of existing teaching facilities, which include those for research, but there is a limit to the useful size of any one University Department. Beyond this its Head ceases to be a source of inspiration, loses all personal contact with experimental work, and develops into a more and more worried administrator. Apart from a few neglected subjects, there is an ample supply of men well qualified for Professorial duties in the new Institutes. I would emphasize that point. We hear much about shortage of man-power, but there is no shortage of leaders capable of developing new institutions of University character.

This matter of the provision of scientific man-power is really pressing. It is being considered by a committee appointed by the Lord President of the Council and we trust that the Report will indicate precise steps to be taken and not merely provide an opportunity for further discussion.*

Research in relation to industry is carried out (a) by individual firms, (b) by co-operative research associations, (c) in laboratories under Government auspices, (d) in University and Technical College Departments, and (e) by private consultants.

It is often described as short term or long-distance, roughly synonymous with *ad hoc*, and basic or fundamental.

I want to dwell for a moment on the extra-mural aspect in relation to the types of research.

The Academic Scientist has the very great advantage of free fishing in all waters and he need not catch a particular fish ; this, of course, easily accounts for his undeserved reputation as a skilful fisherman.

But in this untrammelled pursuit, new knowledge is acquired which can often be utilised by industry, perhaps in some completely unanticipated direction. It is desirable to encourage such exploratory research, and therefore industrialists should make contact with such University Departments as are already attacking topics related to their interests, rather than seek help along lines that have not arisen spontaneously.

There are of course intermediate and exceptional cases and some of the projects proposed by industry may be so broad that ample freedom of choice is retained. For example, it would be quite proper to suggest an examination of the relation of the properties of alloys to structure

* This Report has since been published (May 1946. H.M.S.O., Cmd 6824, 6d.)

but not to set as an objective the production of an alloy possessing some particular property.

Intimate knowledge of the appropriate industry is of the greatest value to a University Professor in his academic work, whatever that may be. It enables him to keep a better sense of proportion, to avoid getting into a rut, to take continuous lessons in his own subject; and in short it acts as a corrective against many of the intellectual maladies to which Professors are apt to succumb.

On the other side I speak with some diffidence, but the evidence is in favour of the view that industrialists in their turn derive benefit from their contacts with the Professors. A notoriously successful example of extra-mural relations was provided by the I.G. for it may be doubted whether any discovery of importance was made in German University chemical laboratories which was not made known to the combine before publication. I do not suggest for a moment that such contacts ought to be confined to the Directors of Laboratories or that this is the only way in which the desirable relations can be achieved. Apart from the use to be made of the actual research carried out in Universities, there is the over-riding consideration that the main function of the teaching institutions is to train students in the methods of research. It is far more stimulating for the beginner to take a hand in the work of his school and thus to get the advantages of discussion with colleagues and enthusiastic supervision than to embark on a disconnected topic, in which his teacher may indeed be interested, but not so interested as in his own work.

The prescription for the attitude of Industry to University Departments is therefore a simple one. Support the Universities, give them their head, and keep in touch with them.

Most of the work of industrial research departments is necessarily directed towards clearly defined objectives. Dependent on the nature of these the probability of a successful outcome ranges from the infinitesimal to the infinite. No generalisation is possible except that the solution of a difficult problem is usually more rewarding than that of a simple one. One of the necessary qualities of a good Director of Research is a capacity to balance his programme from this point of view. There is a fairly close analogy to the work of an Insurance Society, not to say that of a bookmaker.

More germane to my earlier remarks is the question of fundamental research to industry. How fundamental should it be? The answer is again that circumstances alter cases and that attention must be paid to our undoubted shortages of scientific man-power. There is an increasing and very welcome tendency for the larger establishments to

embark on basic scientific research but it will usually be found that there is an industrial objective, although possibly a distant one. Really blind research, industrially speaking, is better left to the Universities under present conditions.

Incidentally, it is now recognised that the prosecution of basic research improves the morale of a laboratory, and in that psychological connection I would put forward once again the not very original pleas for longer vacations for research workers, encouragement of their attendance at scientific meetings, and for permission to publish their results, whenever that is feasible. In many cases that is forcing an open door but the wisdom of a liberal policy in these respects is not universally recognised.

Turning to a much discussed question of tactics my conviction is that the supposed antithesis, between freedom and organisation of scientific research, is false. Individual initiative and originality are not only possible but essential in properly directed teams and contrariwise a team consisting of a super-director in charge of slaves is doomed to failure.

Many wartime collaborative projects could be used in illustration and the one that I know best is that on penicillin. Its story provides a microcosm of the world of research. There was first the discovery of Sir Alexander Fleming, quite unpredictable; then the deliberate *ad hoc*, but fundamental researches of Sir Howard Florey, E. B. Chain and their colleagues. These led to the isolation of penicillin in a concentrated form that could be used for biological experiments, eventually for clinical trials. Their resounding success is a matter of history. The next stage was development, production and all the accompanying refinements of mycological, medical, and manufacturing technique.

I am more concerned with the chemical research which was carried out in this country and in America on a basis of full collaboration. It was an organisation of many teams welded together by a common objective and by full exchange of information supplemented by personal discussions and conferences. I myself attended three such conferences in successive years in the United States.

The teams were formed in industrial research laboratories in Government Establishments and in Universities; they made use of each other's results but preserved their full independence. One such team was formed in Oxford, and regarding that I can say that the individual members of it have always been free to develop their own ideas. Several of them have made original and significant contributions. I believe that the same is true of other branches of this complex

organisation. The outcome is that we have written a new chapter of pure chemistry. It will be described in a book, and the work of putting together about 800 scientific reports that have been submitted is now in active progress. As regards results, using my earlier analogy, we set out to catch a particular species of fish once a day but so far we can only get one specimen every three years. The research is evidently unfinished, but we have learned a lot about the habits of that fish and will get him in due course. Other wartime collaborations have probably reached even greater proportions and may have been even more successful. They will be found to reinforce the argument that team-work can always be expected to facilitate the attack on a difficult problem, and that it is consistent with the freedom of individual scientists to follow their bent within the framework of the project. This does not mean that there are to be no Captains or Generals or that there should be a hotch-potch of unrelated effort inside the team. There must be co-ordination and direction which will be expected and welcomed by the average worker.

On the other hand the conditions must be such that the man with ideas is encouraged to test them. Indeed that should be obvious because it is really the only way to assess his potentialities and to discover the future group leaders and Directors of Research.

This country has been in the past second to none in scientific research and industry, but we are faced with new and harder conditions and must adopt a new technique of development if we are to survive the post-war emergency. The revolution in methods must be of the order of that which has occurred in warfare.

Returning to the starting point, the first desideratum is an extension of scientific and technical education so as to render possible the massing of the battalions of research.

We have bleated and baa'd, sometimes simultaneously we have trumpeted and roared in our efforts to interest the public and stimulate the Government. To some extent these activities must continue, but the papers to be submitted to this Conference are not wholly propagandist. They will deal largely with problems within our orbit and of a practical nature. They deserve the closest attention.

SESSION I

Science, Industry and the Community

ADDRESS (II) BY SIR WILLIAM LARKE, K.B.E.

Lately Director of the Iron and Steel Federation,
Chairman of the F.B.I. Industrial Research Committee.

INDUSTRY'S PART

This great conference has been convened to consolidate on a broader basis the vital collaboration between Science and Industry in this country, without which Victory could not have been won. The achievements of British industry are now a matter of history which the world has acclaimed and of which our country may well be proud. We must remember that this collaboration under war conditions was directed to the obtaining of results in the shortest possible time, since delay involved loss of human life and the imposition of suffering and hardship on millions of people. Cost was of necessity a secondary consideration.

When the ravages of war have been made good, the experience obtained as a result of the production of munitions in all the industrialised countries of the world will find them better equipped than ever before in history and thus able to compete with this country in industries and markets in which before the war our position was pre-eminent.

Collaboration in the restoration of the ravages of war and the recovery of our competitive power introduces a new factor, in that, to technological efficiency must be added economic efficiency in the production of the maximum result at the minimum cost. That this is fully realised by those responsible, and that Industry is prepared to accept the responsibilities implied, is abundantly evident from the widely representative character of this Conference.

In the drive for increased production on which our economic survival depends, and in our efforts to increase the volume of our exports to pay for those imports on which the operation of our industries is dependent, it follows that we cannot rely on expanding our exports of commodities of ordinary consumption which are produced

with equal efficiency in countries now able to supply themselves but which were previously open to us as export markets. We must therefore develop and expand our export trade in products of industries in which the results of recent scientific research are embodied. To these industries we must look for the greatest possible increase in exports in order to compensate for the loss of markets in those industries affected by the new order of competition. Some of the industries on which a particular responsibility will rest are the Engineering and Chemical groups, the newer Textiles (based on synthetic fibres) and those older industries which, based originally on empiricism, have improved and still are improving their products and their practice by the adoption of scientific research and the application of the scientific method. It should be noted that even those industries which by the nature of their products may expect to meet keen competition, can, and doubtless will, by the intensive application of research, so improve or even change the character of their products as to establish a new competitive position in world markets. It is to take counsel together, and to mobilise our undoubtedly great natural resources in the fields of scientific discovery and technological ability in the interests of national (and, indeed, it might be said, world) recovery, that this Conference has been convened.

Our tendency to under-statement and self-depreciation must not blind us to the realities of the position and prevent us from taking encouragement from the lessons of the past, in dealing with the problems of the present and securing a peaceful and prosperous future. It is well to remember what British industry has achieved in the last two hundred years, and the benefits which it has conferred on the social and material life of mankind as a result of the fact that this country was the birthplace of the fundamental discoveries of such men as Dalton, Priestley, Davy, Faraday, Watt, Rutherford and Thompson, these discoveries being translated by industries into the provision of the amenities and services of our daily life. A similar revolution is in progress to-day. Never before in the history of mankind has there been such a flowering of the tree of human knowledge as in the present century, and particularly in this country in the last ten years. The results of the application of that knowledge are even yet immeasurable: for example, in the production of new materials; in medicine; in the internal combustion engine; in aeronautics and in the release of atomic energy, to name only a few of the outstanding groups.

Our purpose is to ensure the maintenance of existing and the creation of additional facilities for the progressive increase of fundamental knowledge on the one hand, and its rapid application to the

service of industry for the benefit of the community on the other. The provision of new knowledge involves the increase of facilities for fundamental research in which those scientists possessing the urge to extend the field of knowledge for its own sake will be free to follow their own inspiration without any pre-determined application. We are fortunate in possessing many such who, with little regard to material reward, are inspired to explore the unknown. The results of their work, however, must be not only available to, but continuously considered by, those who, working in the field of applied science, are able to determine what application can be made of such new knowledge in industry. Thus we in industry, in our effort to achieve a higher standard of life in this country, and to contribute to the raising of standards throughout the world, must assume the responsibilities attaching to the task before us, and through organised opinion, personal co-operation and financial support, ensure that the research facilities of this country are developed and maintained at a level commensurate with its needs, in full collaboration with the scientific community. This connotes not only expenditure on a higher scale then ever before, but also the provision of the requisite man-power, which involves participation in the development of educational and training facilities. There have been many examples recently of the realisation by industry of these responsibilities, and generous attempts to discharge them.

It should be emphasised that the industrial research effort of this country is much more substantial and widespread than is generally appreciated. A recent survey made by the Federation of British Industries has established that there are at present some 9,000 graduate scientists engaged on research and development in British industry; that the total expenditure on such research and development, so far as it has been ascertained, is of the order of £20,000,000 annually; and that those industries which have contributed to the survey propose in the next two years to extend their scientific research staff by no less than 25% and increase their laboratory space by more than 2,000,000 square feet.

The Industrial Research Association movement, which is unique to this country, has been a valuable factor in bringing together Science and Industry and stimulating throughout Industry an active interest in the application of science and the scientific method of industrial practice. I venture to think that the conception of this co-operative movement was a stroke of genius, in that it tempered competitive isolationist individualism, by collaboration in many industries, and proved to the individuals concerned that what they gained from collective work and experience substantially

increased the value of any effort they were able to make working in isolation. Thus the general efficiency, not only of the industry as a whole but of each individual unit, was improved. This movement, although initially of slow growth (owing to the individualism characteristic of our race) is making rapid headway. There are thirty Associations working under the ægis of, and in collaboration with the Department of Scientific and Industrial Research, which makes grants from public funds to the Associations proportionate to the funds provided by Industry : their total annual expenditure is now upwards of £1,000,000. This is far too small (notwithstanding that certain individual associations are already spending upwards of £100,000 per annum), but plans are in progress to pass the £2,000,000 mark within the next five years. One great advantage of this movement is that industries with a small turnover and therefore small financial resources are able to take advantage of the collective research facilities and scientific services thus made available in the progressive improvement of their products and processes. In short, research is a speculation in prosperity ; its neglect, a confession of complacency the penalty for which in a highly competitive world is progressive decline and ultimate bankruptcy.

This, however, inadequately, sketches the background of the present Conference.

I am confident that your deliberations will make a valuable contribution to the supreme effort which British industry is called upon to make, to repair the ravages of war and restore those standards of living which were so cheerfully sacrificed in defence of our national ideals. We may proudly claim that Britain has saved the world by her exertions, and we pledge ourselves that British industry will secure the future by effort and example.

SESSION I

Science, Industry and the Community

ADDRESS (III) BY

SIR EDWARD APPLETON, G.B.E., K.C.B., F.R.S.,

Secretary of the Department of Scientific and Industrial Research.

FUNDAMENTAL RESEARCH AND INDUSTRIAL PROGRESS.

It is, I think, worth noting that one of the few useful results of our recent experience in the war is the lively realization on the part of the general public of what they owe to scientific research. The public has seen how the great triumvirate—the Services, Industry and Science, have worked together and achieved complete victory over our enemies. It has seen, on a background of rapidly moving events, the four stages, research, development, production and application in the field, follow one another so rapidly that the connection between the first and the last has been realised in a way which would have been impossible in the slower tempo of peace-time development. As a result there has arisen in the public mind a strong conviction of the necessity of scientific research as the essential, if not the only, means of ensuring the security of our nation, the success of our industry and the welfare of our people. The public has high hopes and expectations of science in this post-war world and we who are here to-day, whether as members of science or industry, must not disappoint them.

It is no new fact that the scientist is capable, not only of finding out and understanding the various phenomena and forces of nature, but also of controlling or using them for human good or ill. What is new, however, is that the general public is now keenly aware of it for the first time.

During the last century the connection between science and application was not always obvious. Science was usually a very long way ahead of practice, as is witnessed by the long delays which occurred between scientific discoveries and their application. It was not until the early days of this century that science was consciously and deliberately organised on any large scale for the practical end of improving industry or the lot of the people. One of the most important practical

discoveries of this century, it seems to me, has been its discovery of the method of making practical discoveries.

There is no doubt that so far as Great Britain is concerned science was married to the needs of industry and of the community in 1917 when the Department of Scientific and Industrial Research was established. It says much for the foresight and wise planning of our political, industrial and scientific leaders of thirty years ago that the organisation they then devised has survived and been found suitable in structure to meet the needs of the present day. But more can be done and we are trying to do it. To misquote Voltaire " we must not let the good be the enemy of the best."

I am not, however, going to talk to you about what the Department is, or what it does. All of you, or at any rate the large majority of you, know much about it already. You know we encourage research in industry through the Research Associations which receive financial support from the Department. You know also of the work, both for industry and for the community, which is carried out in the Department's own establishments.

There is, however, one function of the Department about which I do wish to say a few words. This is its task of encouraging fundamental research. This duty was laid upon the Department in its earliest days and it is just as important, indeed more so, than it ever was. The reason is this. While the day to day improvements in technical processes come from scientific research usually in the industries which use these processes, the really spectacular advances in industry, and in particular the creation of new industries which may produce great changes in our social habits and modes of living come from fundamental research. The subject matter of fundamental research often seems trivial and gives no indication of the possibility of any practical use, yet time and time again some discovery is made which transforms a whole industry and modifies our way of life. Who could have foreseen that O. W. Richardson's experiments on the loss of electrons from hot wires would lead to broadcasting and that J. J. Thomson's cathode ray tubes would lead to television ? Both of these have created new industries and employment on a large scale and have altered our social habits.

Unfortunately, one cannot tell in advance what items of fundamental research will next prove useful. Only the future can tell that. Meanwhile we can only ensure such results by carrying out enough fundamental research. I do not, however, know any precise definition of " enough " in these circumstances. That is why I think we should do as much as we can and the Department is prepared to play its part in this justifiable scientific gamble.

Now there is one thing about fundamental research which I wish to bring to your notice. The results of fundamental research are published in the journals of the learned societies. The knowledge they bring is, in consequence, at once available to everyone who takes the trouble or has the ability to read them. That is why I advocate that every firm should employ at least one scientist capable of understanding and appreciating potential economic and industrial applications of new scientific discoveries in relation to his firm's activities. The chance is freely given to all who are alert enough to seize it.

There is a variety of fundamental work whose importance I should like specially to emphasise to you. I will call it objective fundamental research. It differs from free fundamental research in that it has an ultimate practical end in view, though its immediate results may not have any direct application. This long-range attack on basic problems often brings valuable results. The following are examples. What are the fundamental causes of warping in wood, toughness in meat, shrinkage in wool, hardening of steel, corrosion of materials ? You can think of many examples yourselves arising in your own industries for every industry is full of them. Now what does the scientist do in such cases ? He seeks, it seems to me, to gain physical insight, chemical insight—perhaps even atomic insight—into these processes. Only by interpreting them in terms of entities which he can understand —atoms, molecules, side chains, etc.—can he feel satisfied that he understands these processes properly. Armed with this understanding he is competent to seek to control or modify them.

We particularly encourage this objective fundamental research work in the Research Associations and in my opinion a considerable amount of it should be done in every reasonably sized industrial and Government laboratory. Often a basic attack of this kind proves to be the shortest and most fruitful road to the solution of problems of practical importance.

My second topic is that of the scientific workers themselves. Do not let us forget that scientific research, whether it be academic, government or industrial, depends on men and on men with ideas.

Now we are going to be very short of scientific manpower in the next few years. This is due, in part, to the war which restricted the opportunities for training except in special directions and, in part, to increased demand, particularly in industrial research, as is disclosed in the replies to the questionnaire recently sent out to industry by the Federation. It is therefore vital that our available manpower shall be used to the best advantage and conditions secured so that our limited number of research workers shall be able to give of their best.

For this to take place our research workers must be maintained in good scientific health. The most effective means to this end is, I feel, to encourage the fullest scientific intercourse between scientists of all types whether they work in Universities, Government establishments or Industry. There is an essential unity about scientific research whatever be the kind of establishment in which carried out. This Conference to-day is discussing Science, Industry and the Community. To my mind all science is ultimately directed to the benefit of the Community and I feel that scientists, whatever kind of establishment they work in, or whatever kind of problem they seek to solve, are essentially working for the benefit of the Community. This common purpose underlying their work seems to me far to transcend any alleged differences between them. I strenuously oppose the view that there are superior and inferior forms of scientific activity according to the type of establishment in which they are carried out. There are scientific workers to whom discoveries are ends in themselves ; there are others who create new knowledge or utilize existing knowledge for the benefit of the community and who derive both mental and moral satisfaction in so doing. They belong to the same family and they all use the same scientific method. During the war they lived together and turned their united efforts to the practical business of winning the war for the benefit of the community. They found as much stimulus and moral satisfaction in applying scientific laws to the practical purpose of winning the war as in discovering them.

I am often consulted by young scientists starting out in life and I count it a great privilege to be so consulted. Although the question of salary is often of considerable moment, I find that they are often concerned with answers to two other questions: " Whom will my work benefit ? " and " If I join this particular organisation shall I cease to be a member of the scientific community ? " These seem to me to be perfectly legitimate questions and, if we wish good men to enter industry, we must be able to give them satisfactory answers on these points. It is a fact that, in the past, if a man entered some of our industrial firms he became completely lost to the scientific world. One never heard of him again. He was not, on principle, permitted to publish any of his work, not even the purely scientific part of it. On the other hand, other firms were just as liberally enlightened and encouraged publication as far as possible. Their staffs made contact with scientific workers in University and other laboratories with whom they discussed scientific problems with benefit to all.

I believe that it is here that we have one of the secrets of the method of maintaining our industrial scientists in healthy condition and of prolonging their useful scientific lives. I believe that the need

of secrecy is unjustified in connection with practically all the purely scientific work which lies at the back of industrial research, and that if one could really get at the facts we should find that industrial firms working in the same field and maintaining a close silence about their research, are very often merely trying to keep each other ignorant of those things they all already know. We must stop all this unjustifiable secrecy, both in Government and Industry.

We must see that workers in Universities, Government and Industry have occasion to gather together, as members of the same scientific fraternity and with an equal right to membership. Only in that way can we be sure that there will be healthy interplay of scientific thought and exchange of techniques which experience teaches us are essential for a virile scientific community.

SESSION I

Science, Industry and the Community

ADDRESS (IV) BY

SIR HAROLD HARTLEY, K.C.V.O., F.R.S.,
Member of the British Overseas Airways Corporation.

INDUSTRIAL RESEARCH IN ACTION.

As I have just ended my active participation in the research organisations of the L.M.S. Railway and the Gas Light and Coke Company, I hope you will allow me to speak this morning of my own experience of science in industry and its service to the community. I have had the satisfaction of watching for 16 years in the one case and 23 years in the other the research laboratories gradually take their proper place in the living organisms of these two companies. I speak of them deliberately as living organisms, as a large modern corporation, if it is to be efficient, must have the sensitive reactions of a living organism and the delicate interplay and co-operation of its various parts, with their instantaneous impulses that traverse the nerve fibres to tell us when all is not well—one of the signals that research is needed.

Are there any golden rules for research in industry? I think there are. Firstly, a sympathetic Chairman, and I was fortunate in serving under the late Lord Stamp, Lord Royden, and the late Sir David Milne-Watson; none of them had had a scientific training, but all had the imagination to see what research could mean to industry. With their confidence in the dividends it would earn, they never grudged the money it cost, but rather asked "Are you thinking big enough?"

You need, too, a good Board to show that interest in their work that means so much to the staff of a research department, and research is a sensitive plant, particularly in its early stages. Science is gradually, all too gradually, finding its place on the Board to ensure that the possibilities of technical development are appreciated and get full consideration in determing policy.

Then you must house research fittingly, functionally is the modern word. All of my Chairmen had an appreciation of good architecture and knew the importance of housing their research adequately in a building that would show other departments the value that the Board attached to research. As an advocate of good buildings, I was at somewhat of a disadvantage, as they all knew I had done most of my own scientific work in a disused college wine cellar; it was

not, however, altogether inappropriate for research on very dry alcohol. And industrial research has often started in a humble way with makeshift accommodation, but the day comes when the palace of science is opened, and the great man, in our case Lord Rutherford, turns the key. Research then has the advantages, the encouragement and reclame that come with a good functional building.

The planning of a research department, the choice of staff, and setting it to work depend on the part research is intended to play. I remember the research director of an American corporation telling me that there are three kinds of research laboratories. " You can have a Monte Carlo by putting a number of clever young scientists in a laboratory, letting them do what they like and hoping for the best. Or you can build a publicity laboratory in stainless steel, fill it with apparatus and let the Press come and see how wonderful it is. Or you can have a laboratory which is attacking directly your immediate problems—the real thing—" by which of course he meant his own. My own experience favours a judicious blend of the three. Two of the most successful research developments, the gas-filled lamp and nylon, came from the fundamental work of Langmuir and Carothers which was not aimed directly at any immediate practical use, although it would come within Sir Edward Appleton's category of objective fundamental research. Publicity, too, is a necessity in our modern world, and if you include in it the publication of papers by the research staff you touch one of the greatest incentives to keenness. It provides also the yardstick of efficiency that comes from measuring the value of their activities alongside those of their colleagues in other laboratories. Members of the L.M.S. research department have a fine record, as in the past ten years they have contributed 95 papers to current literature.

Of the wisdom of directing the major effort of the laboratory to the immediate problems of a business I have no doubt, as it is in that way that understanding and confidence will gradually be established between the researchers and their colleagues, as they show their ability to deal with day-to-day difficulties—" trouble-shooting " as the Americans call it. The successful solution of even these problems is often not a simple matter, and requires not only experiments of a new character but also a close acquaintance with the latest advances in University laboratories. My experience is that it pays, therefore, to recruit first-class men with research experience at a University. Some of them with the stimulus of immediate objectives develop as practical technologists, while others will keep a more detached and fundamental outlook. Together they will make a team equipped to deal with any emergencies or to face the long-range problems of an industry. In the stimulating atmosphere of a successful

industrial research laboratory my experience has been that men almost invariably do better than one might have expected.

Turning first to Railway Research, the L.M.S. Railway, in order to cover the wide scope of its activities, has a research department with six main sections dealing with chemistry, physics, engineering, metallurgy, paint technology and textiles under a Research Manager. A comprehensive organisation of this kind has the advantage of a centralised body of specially qualified workers, trained in scientific method, expert in the use of apparatus and instruments, competent to plan and conduct experiments which will lead to conclusive results. As Midgeley said "the basis of scientific progress is the reproducible experiment." So many industrial experiments have been made in the past without a scientific plan and without the proper means of making or recording the measurements, on the analysis of which the results depend. It is in this way that the L.M.S. Research Department has been most successful by devising new techniques and giving to its conclusions a certainty they could not otherwise have attained. The every day operations of industry are in fact a series of large scale experiments, and it is one of the functions of the research department to see that the lessons are not lost or obscured.

Let me give you a few examples of how the L.M.S. research department has co-operated with the other departments of the railway to give the public greater comfort, greater safety and, what is equally important, to give better service at a lower cost. A passenger's comfort on his journey depends largely on smooth running, which is a function of the track, of the motion of the wheel on the rail and of the springing of the vehicle. Starting with fundamental investigations of the first two factors at Cambridge, the motion of the wheel on the rail was investigated with a cine-camera and a series of field investigations has been made of the relative movents of sleeper, rail and chair, of the service stresses in each, of the effects of high speed trains, and of various combinations of rail type, sleeper and fastenings. The aim was to study the basic theory of the effect of rolling stock on the rails and of the mechanics of the permanent way structure in order to find the most effective and economic solution of the problem.

Safety is the first consideration of the railways. Broken axles due to flaws hidden in the wheel boss have always been a potential source of danger. A method has been devised for detecting their presence at an early stage, even if they are not eliminated completely by a better design based on research. Signals are the safeguards of safety and the cause of the erratic behaviour of one signal appliance, which was causing a lot of trouble, was quickly found with the help of a high speed cine-camera.

In 1939 we foresaw the danger to the signalmen from the effects of blast on the windows of their boxes. Research on the best methods of attaching sheets of cellophane to the inside of the windows was so successful that in spite of many incidents no signalman was seriously injured by flying glass, although in one case one of them was literally wrapped up in the fragments of his window still firmly held by the cellophane lining.

Then the architects have provided one of the best examples of co-operation by bringing in the research department at the planning stage and thus diminishing the need for post-mortems which can only help to avoid similar trouble on future occasions. There, research has helped with the heating and ventilating problems of large buildings, by vibration surveys, by noise surveys to ensure the quietness of hotels and offices without unnecessary expense on double windows and other precautions, and by the study of all the materials to be used in future buildings.

Those are a few of the ways in which scientific research has made its contribution to the problems of the railway and has gradually become an integral part of the organisation. The railway has in fact become research-minded and it is not too much to claim that scientific method, the breaking down of a problem into its component parts, its resolution from first principles, and the use of exact statistical methods, have thereby entered more fully into the daily life of each department.

Turning now to the Gas Light and Coke Company, the picture is much the same from the time when research had to find its own opportunities until the engineers learned to look to it not only for the solution of their immediate difficulties but for guidance in their long distance plans. And now they pay it the compliment of trying to steal research staff for executive jobs. When that happens you know there is not much wrong. Once again the policy of recruiting the laboratories with men of high academic standing and research experience has been amply justified by their adaptability in bringing scientific analysis and experiment to bear on the problem of making gas and in using it with the maximum efficiency for an ever-growing range of purposes.

Attention is often drawn to the long interval between research and its large-scale development. In the Gas Light and Coke Company this has been largely eliminated by the close co-operation between the engineers and the research staff, who, thanks to this, have always in view the engineering problems involved in the application of their research.

The chemists have brought new light to bear on the process of gas making and its scientific control, the results of which are seen in its increased flexibility and efficiency. Their most striking work has perhaps been in the re-examination of the traditional methods of gas

purification to meet the higher standards of improved service to the public at lower costs and incidentally to obtain the maximum yield of benzol which was of such vital importance during the war.

In the utilisation of gas the work of the research laboratory at Watson House has been equally productive. Each aspect of the use of gas or coke has been subjected to scientific analysis and the results have helped materially towards the greatly increased efficiency, convenience and appearance of modern gas and coke appliances.

In all these ways the Research Departments have contributed towards what I have called the Domestic Revolution of the twentieth century—the scientific application of heat and power in the home, which has done so much to raise the standards of health and comfort and to lighten the burdens of the modern housewife. It can be regarded as the repayment by the technician of a debt long overdue for some of the social evils that sprang from the Industrial Revolution of the last century. In this field science in the service of the community is seen at its best.

It may be urged that my experience of industrial research in two companies big enough to affort large well-equipped laboratories and ample staff is of little assistance to smaller firms of which there are so many. But even a small firm could have one member of the staff with a scientific training to watch its activities, to keep in touch with outside developments, and to see what science can contribute to new methods and greater efficiency. Smaller size undoubtedly makes the problem more difficult, but the need for science is the same, and in the small firm it may pay even a larger dividend.

The modern trend is, however, towards amalgamations and increased size. Elton Mayo, in his recent book " The Social Problems of an Industrial Civilisation ", in which he has contrasted the problems of the established society of the nineteenth century with those of the adaptive society of this century, has drawn attention to one of the social dangers of this increase in size. If a small firm should go out of business for any reason the chances are that others are developing in the neighbourhood, and there is no serious incidence of unemployment. Should, however, a large modern corporation employing thousands of workpeople fall on evil days, the resulting unemployment may become a community problem of the first magnitude. But scientific research can go a long way towards safeguarding the prosperity and stability of these large units by preventing obsolescence. When we are ill we send for a doctor. He may delay but he cannot prevent old age. Research is the elixir of life of industry, ever renewing its youth and vigour. Where research is intelligently applied, old age is impossible.

SESSION I

Science, Industry and the Community

ADDRESS (V) BY

SIR ERNEST SIMON, LL.D.,

Chairman of the Council of Manchester University.

THE PART OF THE UNIVERSITIES.

The change in public opinion in the last two years as to the scale on which scientific research and development ought to be carried on in this country has been revolutionary. As regards industry, this authoritative Conference provides conclusive proof that leading industrialists have made up their minds on the matter. As regards the Government, Mr. Strachey stated in Parliament the other day that the gigantic sum of twenty-eight million pounds is to be spent on aviation research and development in the coming year and that he regarded this as " a small and modest figure in view of the importance of the subject." This statement seems to have been generally approved by Parliament. The expenditure on aviation research will be twice as much as the total expenditure, even on its increased scale, for the whole of the universities of Britain.

The battle for full recognition of science is won. The problem now is to get quick and effective development.

One vital aspect of the problem is the provision by universities of greatly increased numbers of scientists. I am closely concerned with this problem as Chairman of the Council of Manchester University, and should like to consider what the demands on the universities are likely to be and whether and how the universities can meet them.

It is understood that the Committee appointed by the Lord President of the Council to consider this matter will report very shortly.* Meantime there seems to be general agreement that the aim should be to double the number of science and technological graduates turned out by the British universities in the next ten years. I shall assume therefore for the purposes of this discussion that that is the task before the universities.

* This Report has since been published (May, 1946. H.M.S.O. Cmd 6824, 6d.)

Unfortunately it is not possible for all the universities to double their output of scientists. It would be very difficult for Oxford and Cambridge with their college system; and they are already about the 5,000 mark which is beginning to be regarded as the upper limit for the effective organisation of a British university. Edinburgh and Glasgow, and a considerable proportion of London University are also unlikely to expand. This covers about half the number of students in Britain. The remaining half, that is to say roughly the provincial universities, would have to treble their output of scientists to meet the bill. I hardly think this is regarded as practicable; if the provincial universities doubled their output of scientists in ten years that would be a considerable achievement; the remainder would probably have to be provided either by the promotion of colleges into universities or by the founding of new universities. In any case it is clear that the main task of educating the additional scientists must fall on the provincial universities.

There are two preliminary points, with which I am sure there will be universal agreement; firstly, that under no circumstances will the universities allow their standards of education to be reduced; secondly, that under no circumstances must the academic freedom of the universities and of their staffs be interfered with. These must be regarded as fundamental conditions of any scheme of expansion.

There is another matter which is of immediate and urgent importance. There are a large number of high quality ex-servicemen and others who will be available to the universities during the next few months and who should undoubtedly be taken into the university science departments. But there is a serious bottleneck in the lack of buildings and equipment, and the universities are finding great difficulty in securing the necessary licences and priorities. Their total demands are small, but unless the government departments concerned give much more active help, many of these men will be permanently lost to the country as scientists.

May I now turn to consider what are the long term conditions necessary to enable the provincial universities to double their output of scientists in ten years without lowering standards.

(1) MONEY:

Universities will need considerable grants both for capital expenditure on buildings and equipment and for annual expenditure on staff and maintenance. It is probably true that no science department in any provincial university has hitherto had the necessary facilities and staff to enable its leading members to do their best work in research. In comparison with American universities our science departments have been starved.

Before the war the income of the universities was six million pounds per annum, of which about a third came from the Exchequer. Last year Sir John Anderson increased the Exchequer grant by three and a half million pounds ; this year Mr. Dalton has already announced a further increase of about the same amount. Next year the income of the universities will therefore be about thirteen million pounds of which over two-thirds will come from the Exchequer. This must be regarded as satisfactory and as affording proof that the Government intends to provide the necessary finances to enable the universities to expand as required. But it will be agreed that it is undesirable for the universities to be too dependent on one source of income. It is to be hoped that private benefactors and industry will continue and increase the generosity they have shown in the past ; if possible on a scale more nearly approaching what has happened in the United States. There are encouraging signs of a movement of this kind.

(2) STAFFS :

The most serious difficulty will be to increase the teaching and research staffs of the universities on the necessary scale and with the necessary speed without lowering the quality. One important factor is that both the Government and industry are paying much higher salaries for scientists than the universities have hitherto been able to afford. It is true that many scientists prefer the freedom and amenities of university life and are prepared to accept lower salaries for these reasons. There are scientists in Manchester University who could double their incomes by accepting a post in industry. But this cannot be carried too far, and it is essential that there should be a reasonable balance between the incomes of scientists in the universities, in industry, and in the government service. If the Government and industry use their full powers to attract too many of the best men, then the universities will fail in their task.

(3) UNIVERSITY RECRUITING :

There is one other condition of success. The secondary schools must produce enough students of the necessary quality properly prepared for entry to the universities. It has often been suggested that the doubling of the number of university students would necessarily mean a lowering of quality. This matter has been regarded as so important in Manchester University that an enquiry has been carried out into the Intelligence Quotients of the students at the university, and they have been compared with the I.Q. of a representative sample of the whole population. Though the report has not yet been published, I think it permissible to say that the results are highly encouraging. Half the students at Manchester have an I.Q. of 127

or more. Assuming that these are representative of the universities as a whole, only one-sixth of these highly intelligent young persons are at the universities ; no less than five-sixths of them miss a university education. If we get them all, *it would be possible to treble the number of university students, while excluding the less intelligent half of those who are now at the universities.*

This failure to get the best young persons to the universities is I believe disastrous for the nation and a severe reflection on our educational system. I venture to suggest that the most urgent task in front of the Ministry of Education is so to adjust their whole system of secondary school education, maintenance allowances, scholarships, etc., that a much greater proportion of the best children will, regardless of the means of their parents, be made available for university education.

Conclusion :

To sum up, the task before the provincial universities is to double the number of their science graduates within ten years without lowering standards. This is possible on the following three conditions : firstly, adequate grants from the Government or other sources both for capital and income. Secondly, that the salaries of university scientists should be comparable, with due allowance for different conditions, with those payable in industry and in the Government service. Thirdly, that the Ministry of Education should ensure that the necessary number of students of the highest qualifications and with the right education shall be available each year for entry to the universities.

Given these three conditions, the rest is up to the universities, and mainly up to the provincial universities. From my intimate experience in one of these universities I am confident that they will amply fulfil their responsibilities.

SESSION II

SCIENTIFIC RESEARCH AND PRODUCTION

CHAIRMAN : THE RT. HON. JOHN WILMOT, J.P., M.P.,
Minister of Supply.

PAPER I

RESEARCH AND QUALITY

By J. R. HOSKING, Ph.D., B.Sc.,
Director of Research and Development, Paints Division I.C.I., Ltd.

Before illustrating with brief examples the part that can be played by research in maintaining or improving the quality of industrial products, a few general observations might first be made upon the importance of " quality " in industry.

The continued prosperity, in fact the existence, of almost any industry we care to name, whether it be concerned with the production of raw materials or of finished manufactured goods, is dependent to a large extent upon the maintenance of the quality, set as a standard, of its particular products, and of its ability actually to improve the quality of these products. The quality factor becomes in general the more significant as the number of industrial units producing the same type of material or goods increases, in other words, as competition for markets increases.

Quite small differences—some would say insignificant differences—in the quality of a chemical or the behaviour or appearance of a finished product, may be of immense importance when it comes to marketing. In the case of export markets the quality of one's goods becomes a factor of national importance. Good quality is probably the forerunner of goodwill, and it is frequently the case that goods for export are maintained at a higher standard of quality than are those available to the home consumer. Especially in the case of exported foodstuffs is this difference in quality noticeable. Again, this has to be accounted for by competition, in this case world competition, a type more difficult to meet as a rule than home competition, because the

customer has a large choice of suppliers, can afford to be more discriminating, and will doubtless buy the best quality obtainable at the most favourable price.

In Great Britain we are at present contemplating the difficult task of re-establishing many of our pre-war export markets and the opportunity is also presenting itself of opening up new markets abroad in territory we have never before supplied with certain types of goods. The consumers in these countries, although no doubt willing to do business with us, will, however, be critical and tend to compare the quality of our products with those they were able to obtain previously from other sources. It will in great part depend upon the quality of our products and our willingness to supply according to the standards desired by the customer, whether we shall be able to maintain these markets. This, of course, is quite apart from economic considerations which are not the subject of this article.

We have become accustomed to seeing the label "war-time quality" and of being able to sell any sort of product almost regardless of its quality during the war. It has become the fashion to disregard, for example, the outward appearance of our goods, and we often hear the remark: "Provided the machine works, why waste time and money making it look pretty?" In the writer's opinion it is important that we give attention, not only to the excellence of performance of our machines, chemical products, and scientific apparatus, etc., but also to their outward appearance and finish. The better finished article is frequently preferred, as one is tempted to argue (not, of course, always logically): "Well, seeing the finish is so poor, has there been equally little care and attention given to the details of the mechanism? Will it work with precision?" An industry striving to maintain a high standard of quality and by research work to produce goods of still better quality, exerts a good influence on its employees, who generally like to be known as makers of high class materials, and it is very desirable to infuse this "pride of craftsmanship" into our factories.

In setting up a fixed standard of quality for finished goods, the research worker is guided very largely by what the sales organisation has to tell him, as sales representatives are familiar with the customers' desires, views and requirements. Having ascertained the facts, it then becomes necessary for the research department to discover whether such a product, having the required properties and performance, can be made, and if so, the best method to be adopted in producing it in the plant. For such work small-scale plant is desirable. The Research Department may also have to devise new or special tests suitable for controlling the purity and physical properties of the product, especially if new raw materials having special

properties should be required. The Production Department must be instructed in the first place of any new manufacturing conditions necessary for the modified product, and this department must be aware of the effect of its plant and equipment on the behaviour and properties of the product. Existing plant may not be suitable and new plant to suit the particular process may have to be installed, which in the chemical industry may involve a considerable amount of investigational work concerning, for example, the type of metal to be used for construction of processing vessels, design of heat exchanger, stirring gear, filter and the type of filtering agent necessary, etc.

To provide more detailed illustrations of how research may be utilised for the improvement of quality, reference may be made to two industries which are closely associated, the first producing, in fact, one of the raw materials used to a large extent by the second, namely, the synthetic resin and the paint industries.

Variations in the properties or composition of raw materials used in the manufacture of finished materials is a difficulty which has often to be reckoned with by the manufacturer in maintaining the quality of his products. Such variations can be the cause of what is known as batch-to-batch variation, and renders hazardous a smooth and certain repetition of finished products characterised by identical properties and behaviour. Such products are frequently called " reliable " and many firms depend upon the standardised quality of their goods to ensure a continuity of their prestige or good name.

This difficulty of raw material variation has long been associated, among other raw materials, with the resins. The demands made for surface coatings possessing a variety of improved properties have been met successfully by the paint manufacturer in many cases as the result of an immense amount of research work devoted in recent years towards the production of synthetic resins. Until relatively recently, the only resinous materials available to the paint manufacturer were the natural resins, chiefly of vegetable origin, and usually imported from far lands, many of them diminishing in quantity as time went on, for there is no adequate means of replacement. Such materials varied very considerably in composition and properties as well as price, and moreover, in view of their intrinsic properties, limited the paint-maker to certain types of surface coating. The availability of the synthetic resins has largely overcome many of these difficulties, as these resins are manufactured to a standard specification and important properties such as melting point, viscosity, colour, acidity, etc., can be reproduced accurately and modified to suit some special performance demanded by the paint maker. Surface coatings having improved resistance to the solvent action of petroleum or mixtures of petrol

and water, of acids, alkalis, corrosion by sea water, to outdoor weathering, and varnishes capable of withstanding the action of fruit juices, for the insulation of electrical wire, etc., or waterproof varnishes for paper, and finishes capable of withstanding low temperatures without loss of flexibility, etc., are a few examples of the varied demands made on the paint manufacturer which have been met largely as a result of improvements to the resinous component.

In view of the strides made by the synthetic resin manufacturers, who succeeded so markedly in improving the quality of their products, the natural resin producers have turned their attention to the application of further research to natural resins. They have already effected improvements in quality of natural resins by careful grading, removal of impurities by new methods, chemical treatment such as esterification, blending with synthetic resins, etc., and produced products more suitable for use by the paint manufacturers.

The resin manufacturer, in order to improve the quality of his products, is making constant demands upon his raw material supplier for raw materials of better quality, who may then himself become involved in research work into methods for producing better coloured and purer phenols or phenolic substances having substituent groups in certain positions on the aromatic nucleus which are known to convey certain properties in the paint film, for example, flexibility or absence from yellowing. The resin maker is concerned also with the degree of purity of such substances as glycerol, formaldehyde, rosin and phthalic anhydride, and no doubt the phthalic anhydride manufacturer passes his demand for increased purity on to his naphthalene supplier.

The resin is, of course, not the only raw material which may be modified and improved to influence the quality of a paint. This industry uses a great variety of other raw materials such as pigments, fatty oils, plasticisers, cellulose derivatives, solvents, and driers, to mention a few, and the work involved in improving these materials carries their manufacturers into many and varied fields of scientific research, the success or otherwise of which is reflected in the wares of the paint manufacturer.

It is therefore apparent that much of the research work appertaining to the industries mentioned is closely inter-related, and we should be fully alive to the mutual benefits these industries could attain by the fullest possible exchange of views and co-operation on the part of their various research and related departments.

A considerable contribution towards solving many problems of a fundamental nature which are of common importance to any such group of related or closely associated industries, would be an expansion

of the Research Associations. It is not always possible for the research laboratories of an industrial organisation to undertake investigations of a fundamental type, as there always seem to be a great number of urgent problems awaiting investigation, and the longer term research tends to be put aside in favour of the shorter term problem.

Returning to the paint industry itself, we might review briefly in what direction research work is pursued in order to provide surface coatings of improved quality. Paints for finishing metal articles which have a high degree of gloss may be demanded. This involves a study of the influence of the oil, the pigment, and the resin on paints which dry with a glossy surface, and the physicist is concerned with finding a satisfactory and accurate method for measuring small differences in gloss. The organic chemist, on the other hand, will be concerned with methods for suitably modifying the fatty oil and resin. Surface coatings with higher drying speeds are continually being asked for. Investigations must therefore be carried out into the action of certain metallic oxides or driers on the fatty oils and the influence of the degree of unsaturation in the fatty oil molecule. Again, paints are demanded for preventing the growth of marine organisms on ships, so-called "anti-fouling paints," and here the task of improving such paints demands wide facilities for biological research in order to establish the types of organisms we have to deal with, their life cycles, and sensitivity to certain toxins contained in the paint film.

In determining the value of a certain coating composition made from a paint or varnish, we are led very largely by differences exhibited in its physical properties from those of some standard which we consider satisfactory. It is therefore important that we should be able to measure such properties as flexibility, brittleness, adhesion and hardness. These measurements must be capable of indicating accurately small differences in these properties, otherwise we are unable to measure the degree of success we have had in effecting an improvement. The devising of adequate tests for this work is one of the most difficult problems of paint evaluation.

A further instance where an improvement in quality has resulted from research is to be found in the metals industry. It was found, particularly during the war years, that under high pressures a proportion, not infrequently as high as 80 per cent., of ferrous and non-ferrous castings were porous to fluids such as water, petrol or oil. This porosity was a source of difficulty, and resulted in the discarding of a large number of castings. It is of course true that only a minority of castings is required to withstand the conditions referred to, so that under normal conditions, porosity is not a disadvantage and in no way detracts from the performance of the casting.

Many attempts have been made to seal castings effectively, and some improvement in stopping slight leakage can be effected by allowing ferrous castings to rust in ammonium chloride solution. Treatment with oxidised linseed oil is also used, but both treatments are by no means adequate. It was found, however, that very much more effective results could be obtained by impregnating castings under pressure with varnishes containing phenol-formaldehyde resins and stoving the impregnated castings at an elevated temperature. By this means the varnish penetrates into the castings and is converted by heat into a resinous material having remarkable strength and resistance to chemical attack. This process is also used with success where repairs have been made to old castings and it is necessary to seal the pores completely where the inlay has been made.

Finally, it may be pointed out that the benefits of much research work on the improvement of quality of goods may be entirely lost if sufficient care and attention to detail is not paid by the production or manufacturing departments. Considerable advances have been made, for example, in improving the colour of a resin, which would enable it to be employed for the manufacture of the palest coloured varnish or the purest white pigmented enamel, but carelessness in its large scale production, as improperly cleaned processing vessels, or incorrectly controlled temperature increase, or again access of too much air, etc., might easily nullify the whole improvement in quality. This calls in general for highly trained plant operators, careful supervision, and good plant constructed of the most suitable materials.

SESSION II

Scientific Research and Production

PAPER II

RESEARCH AND PRODUCTION COSTS

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Research and Common Sense

This industrial era has been founded upon adventure, not so much into new lands, as into new domains of knowledge, into new applications of knowledge to the problem of satisfying the material wants of people. One must presume, from the fact of being asked to write this paper, that there are still men who, so far from recognizing the real foundations of their industries, continue to believe in themselves as adequate to solve all problems of the future on the basis of common sense and hard work. What is common sense? If a piece of iron is to be fashioned, common sense dictates that it shall be made red hot, that it should be beaten with a heavy hammer. Common sense decides what tools and machines to use to gain certain ends. There is thought to be nothing scientific about it. Yet what is now "common" knowledge, "common" sense, was originally the knowledge of the few, and more often than not, was subject in its pioneering days to obloquy, to charges of witchcraft even. It is true that we can carry on, using all the accumulated scientific knowledge of the ages, and calling it common sense. We can carry on for a time, at any rate. Unfortunately, much scientific knowledge which we affect to belittle, may have already become "common" sense among our competitors, at home or abroad.

When we speak of science and scientific research, we are speaking of up-to-date sense, that is going soon to be common, and of the adventure into realms of knowledge, which will assuredly add to the stock of common sense. "Industrial research," in its meaning for the purposes of this paper, is quite simply "making use of all the available sense there is, by applying it to achieve our industrial objectives."

The old hand, the self-styled practical man, is using always the materials and tools of "science"; much of his self-gained knowledge is indeed scientific—and great credit must be given to the industrial pioneers of the past and present, who would blush to be called scientific, but who are so in essence. To these practical scientists one might say "Good! but remember there is a great wealth of knowledge, a veritable mountain of common sense, at your disposal. Neither you nor any man can know everything. Take all possible steps to pick out what is likely to be of use, and try to apply it to your work."

The word "Industry," in the context of this Conference, means the processes of obtaining, treating and combining natural products, so as to give the public what they want, where and when they want it. In Industry, the application of human knowledge (science) has made revolutions, and revolutions still take place, not necessarily dramatic upheavals, but none the less complete transformations spread over many years, as the result of steady and multifarious applications of knowledge.

The benefits derived from the struggle to increase knowledge are not confined to the participants in that struggle. The advances made by scientific research are not limited to the research workers and those employing them. Many a "practical" industrialist, with a great disdain of "science," has, during the past decades, taken advantage of science, whether by buying better or cheaper materials, more efficient machines, or in imitating others.

It is evident that no industrial unit can be successful unless the best available knowledge is applied to it. Moreover, the most successful industrial units must be those where that knowledge is right up-to-date, and where the *application* of it is most complete. What we as a country are concerned with to-day is not so much whether we have as much knowledge as other countries (although we excel in the field of knowledge), but whether we are making the fullest use of that knowledge in our industries.

The application of scientific knowledge to industry demands the co-operation of the industrialist with the scientist. Neither can of himself visualize the possibilities. When we speak of industrial research, in the context of this conference, we mean not fundamental research into the great laws of nature, but investigations into the possible use of scientific knowledge in solving the eternal problem of providing better *or* cheaper, often better *and* cheaper, products, to the ultimate end that mankind shall live on higher standards of material life, simultaneously with less time on that kind of work called "drudgery."

When it is realized that every industrial unit, whatever the degree of scepticism, of disdain, shown by the owner or manager, is itself the result of a century or more of scientific progress—and applied science—the dependence of its future development on science is obvious.

But while hatred of science has given way to a mild disdain, or even to good-humoured tolerance, during the last fifty years, we have not yet, as a nation, become whole-hearted enthusiasts—in spite of the obvious success of many enterprises great and small, who have for long "believed" in the value of science. There must be thousands of undertakings who think they can carry on in the future as in the past, relying on common sense and ability.

Some Practical Examples

I have been asked to deal especially with the relationship between research and production costs, and to this end the following examples are quoted:

1. In the rubber industry, the crude material is mixed with sulphur and heated. In due course, an elastic substance, quite unlike the original, is formed. For many decades, the process remained very slow. Since 1915, however, as a result of chemical research, the process (vulcanization) which originally occupied 100 minutes of valuable plant, moulds and factory space, now occupies less than 30 minutes. This represents a cost saving equal to one-quarter of the whole labour cost in a rubber factory, besides increasing flexibility and facilitating changes of design due to the reduction in the number of expensive moulds required.

2. Electronic Heating: This method, itself the outcome of applied physics, is only just beginning to be applied to industrial operations. The factory research worker does not have to be a pioneer in theory, but he must understand the theory, the practical problems of the factory, and find ways and means of applying the theory. When large masses of material, having low conductivity, or requiring drying, or both, have to be uniformly subjected to a certain temperature, the saving of time by using the electronic method can be very great. Reductions of process time from say 100 minutes to four minutes are common.

3. Bicycle tyre valves used to be made from brass rod of the same diameter as the head, which was more than twice the diameter of the barrel, and there was much loss of time and waste of material involved in turning down the rod to size. After many attempts, a "heading" process was introduced successfully. It seems the obvious

thing to do, but the metallurgists were busy for a year or two, trying to find a type of brass which would have all the required characteristics in the finished valve, and yet form a " head " accurately and without splitting. The saving was very small, per valve, but over the millions of valves made annually, the savings were reckoned in tens of thousands of pounds sterling.

4. Aluminium used to cost £18 per lb. in 1885, but as a result of chemical and electrical research, an electrolytic process was evolved, reducing the price to £1 per lb. Very soon after, further research work reduced the price to 10d. per lb.

5. Many continuous industrial processes, such as extrusion and welding, are limited in speed. Sometimes the material itself will be spoiled by overheating if the process is speeded up, sometimes the dies and tools will not withstand the strain of higher speeds. There are thousands of practical examples of improvements in this field. Tool steel development has greatly reduced the cost of production in every machine shop in the country. In the rubber industry and others, plasticisers have been evolved in recent years, enabling processes to be carried out much more quickly.

6. Substantial labour savings, with improved quality of product, are often achieved by the use of automatically controlled welding machines. Once the ideal temperatures and times for the welding and the annealing process are accurately known (a piece of research work in any given practical case), an automatic machine can be provided to do the work, eliminating much labour.

7. Variations in the results given by a process, giving scrap and defective work, delaying workmen, hindering output, are the bugbear of production managers in most industries. Apart from the heavy losses involved, it is common practice in laying down plant to make an allowance for " troubles." This is a profitable field for the research worker. By careful observation, and statistical survey, he can determine the most dangerous variations and correct them, whether by the use of thermo-regulators, by the modification of the materials, by closer supervision, or by altering the method employed.

8. Research is not, however, confined to factory problems. A detailed and accurate knowledge of the use to which industrial products are put, of their behaviour, of the public's reaction to them, all forms the subject of research. Obvious examples well known to all of us, are, research on the flight of a golf ball, on proper lubrication of pistons in motor-car engines, on razor-blade steel, on the wearing qualities of cloth. This kind of research may be directed mainly to satisfying the public wants, but it is just as likely to lead to improved

methods of production, to reduction of unnecessary labour and of material for which the public receive no service value.

9. When a product has been scientifically designed, all parts will have definite dimensions and tolerances, large or small. Very often a design specification may give a minimum with no maximum. The industrial problem is to work as closely as possible to the minimum, because the designer has in effect said "The extra material involved in exceeding the minimum is not necessary, and is therefore wasted." It is obvious in this case that the process which gives consistently a dimension very close to the minimum is the most efficient. In many industries, thin sheets or films have to be made, sometimes as thin as one-thousandth of an inch. To obtain a film which is always between .0010″ and .0011″ is not easy. Even then, the inaccuracy is 10 per cent., and where materials are expensive this tolerance may absorb all the profit. There is a great wealth of experience in this field, yet improvements are continually being made—the latest discoveries of pure science are being applied to measurement, and to automatic control of fine gauges. In the rubber industry, the rolling mill for making film (calender) may well produce £1,000,000 worth of film annually. An avoidable error of 5 per cent. represents a loss of £50,000 annually. Small wonder, then, that the rubber calender is controlled by an elaborate set of instruments, that its rolls are ground to an accuracy once thought impossible, and that the scientific workers give constant attention to the problem.

10. It is true that scientific instruments, indicating and controlling thicknesses, weights, temperatures and times, can be bought, but one should not be satisfied merely to buy them. Years ago, not so very many, the best optical instruments came from Germany. May not this have been due to the demand by German Industry ? This would indicate that German Industry in some respect was more scientifically operated, and only after some years, when the instruments found their way on to the market, could other countries take advantage of them.

The Individuality of the Production Unit

Not only each industry, but every unit in an industry, has its own special problems. Local variations in cost and quality of services such as water, gas and electricity, in the character of labour available, and so on, give scope for special study if the best is to be achieved. The managements of manufacturing units have their own ideas, they have a certain confidence in themselves, even a sense of superiority over others, and this, of course, is to be encouraged, as being fruitful of improvement. Side by side with this spirit there must be an

up-to-date knowledge, and a readiness to apply it, from whatever source it comes. The more "individual" a manufacturer considers himself to be, the more he must find out for himself, the more research he must undertake.

Research in Relation to Size of Unit

This last observation brings us to a consideration of the minimum size of a unit which can support "research." To many minds, the large research laboratories and staffs of the great corporations suggests automatically that research is not for the smaller unit. How can they compete ? They do compete, however, and there is a good reason for their relative success. To understand this, it is necessary to distinguish between the research directed to fundamental questions, such as the chemical and physical interpretation of the colloidal state, of polymerisation, of the radio-active elements on the one hand, and that of the immediate application of knowledge to current procedure on the other. The research worker in a smaller unit, which might pay his salary without embarrassment, in collaboration with an active and broadminded manager, can excel in application of science. He knows about radio-activity and ionisation, and can avoid risks of fire due to static electricity. Or he understands colloid chemistry and can deal quickly with a glueing problem. No one realises better than the managements of the great corporations the value of this application, and often they decentralize their operations to take better advantage of it.

Perhaps enough has been said already to indicate that contribution to a Research Association is not in itself enough. An Association is of great value in connection with the more general problems of an industry, such as

(a) Cylinder lubrication
(b) Detonation in internal combustion engines
(c) Effect of heat and moisture on cotton
(d) Improvements in materials used by the industry
(e) Determination of general specifications.

In this field, many Associations have done immensely valuable work. It is usual also for an Association to have a reference library—a great help to individual members, who wish to take advantage of all new knowledge.

There must always remain the individual problem, and it must be tackled individually. The presence of scientific workers, first engaged on known problems, will very soon bring to light other problems and other possibilities, not hitherto known to exist.

Co-operation between Manager and Research Worker

A word needs to be said about the conditions in which the research worker may work most successfully. In industry, the " old hands," apt to pride themselves on having no " scientific education or knowledge " (a mistaken notion, for they have a great deal), have learned much from "trial and error," "rule of thumb," sweet and bitter experience, and are extraordinarily skilled in their art. The young research worker may be over confident, but if he is honest he will soon come to admire the " old hand," while simultaneously finding the problems of industry are not so easy as he expected.

To cite a technical case within the author's experience ; it was the practice in the rubber industry, before the days of instrumentation in the industry but not before the days of science, for experienced foremen to determine the quality of their products by biting them and by pressing on them with a blunt instrument, such as a pencil. After a period of some 20 years of close study, and particularly of the development of new testing methods, it was still the case that by biting and pressing with a pencil, a very accurate gauge of quality was made. The real difficulties, however, with this kind of test, are that opinions vary as between different biters and pressers, and their knowledge can with difficulty be transmitted to the large number of inspectors and testers required in modern industry, and that biters may unfortunately lose their teeth !

There must obviously be a frank exchange of experience, the problem must be fully stated. As we are concentrating on " production costs," it is pertinent to remark that the research worker who is expected to get results must know all the elements of cost as they exist.

In different industries, the costs differ in their make-up. Two examples are given :

	A	B
Material used	70	10
,, unavoidably wasted	5	—
,, otherwise wasted	2	1
Labour	8	40
Supervision and inspection	2	20
Services (water, gas, etc.)	2	10
Technical services	2	3
Management	5	10
Fixed expense	4	6
	100	100

" A " might be a rubber product, " B " a product such as a sewing-machine or a wireless-set.

With figures like these before him, combined with a scientific appreciation of the products and processes, the research worker can determine his most useful target. In " A " he would probably give greatest attention to the material used and wasted, while in " B " he would consider the processes and the tolerances.

By close collaboration between manager and research worker, the most hopeful line of attack is followed up, and all necessary facilities are given. The management too must have faith and patience. How often have initial failures been seized upon by management as an excuse for stopping the research

Relative Cost of Research

This paper on production costs would not be complete without some remarks on the cost of research, which must eventually appear in total product cost.

Much has been written on this, and some authors have given tables and charts as a guide to the expenditure on research which should be undertaken by firms of varying size. While these tables are of interest, they are unlikely to influence the unbeliever ! Another method of approach, still a general one, but not quite so general as that just mentioned, consists in a study of whole cost, and the possibilities of saving. A factory consuming annually £100,000 worth of materials, might usually expect to save 2 per cent. or £2,000 annually, at the least, by the application of the latest scientific knowledge and method. This saving would justify the employment of a research worker or two. Labour and inspecting costs could be similarly studied. It is a narrow view, but it is almost certain to lead to a broad one, if followed up.

Conclusion

To conclude, and to summarize, this country has held its own and more in the domain of fundamental scientific research. The weakness lies in the slowness of our applications of the results to our industrial processes, partly due to ignorance, partly to prejudice, partly to over confidence in individualism. The object of this paper is to make a plea for individualism of the strongest kind—well-informed and progressive individualism.

SESSION II

Scientific Research and Production

PAPER III

CONVERSION OF THE RESULTS OF RESEARCH INTO PRODUCTION

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The First Stage

Industrial research normally starts in the laboratory and stays there in the hands of laboratory personnel until there is a sufficiently definite indication of a useful practical result to justify entering upon its application to the factory. This is its first stage ; up to this point the scientific worker usually has things in his own hands, and he has mainly himself to blame if he is unsuccessful in solving the scientific aspects of his problem. Sometimes his practical result takes the form of an entirely new product. Much more often, by removing the empiricism in some process, he obtains a new insight into its essentials and is able to put forward some radical improvement.

For example, we have a raw material in powder form—it may be a metal or alloy, carbon, ceramic or chemical powder. The article made from it is not always the same, at least it does not appear to behave so. We apply our scientific skill and methods to detect the reason for the difference and obtain what appear to be clues which give us confidence for the next step—*if we are in a position to take it.*

Or a piece of apparatus, be it car or lamp, radio valve, refrigerator or steam turbine, which for some obscure reason gives disappointing results in the hands of the user. Scientific investigation follows and an apparently good clue is obtained. But what is the next step ? *Are we in a position to take it effectively ?*

Perhaps the product of a factory is very un-uniform ;—wastage is taking place, but there appears no obvious source of trouble. In the absence of scientific investigation guessing and random shots are made, and trials result from which far-reaching deductions are drawn, but

somehow things don't get better. The research staff are brought in, and maybe they find that by analysing statistically some of the data of the processes, the deductions are not justified. The clue therefore points to an obvious but difficult course of action ; i.e. the institution of proper quality control of the factory production ; *but are the research personnel of the laboratories in a position to follow this up ?*

We may take one other case :—a factory runs fairly economically and well on a product with certain tolerances and margins in its components and processes. It appears to outsiders, from calculation and theory, that a new and advanced product would result from the adoption of much finer tolerances and narrower margins. Provisional prototypes are made by the laboratories to establish the case. Research has thus done its proper part, but successful consequences are not automatic ; *how is the matter to be followed up ?*

In all these cases we see scientific workers applying their investigatory techniques up to the limits of normal laboratory experiment and research. Given the necessary expert knowledge of the industry, good team spirit and leadership, and any of these problems will be carried to the point where it seems on the way to being solved.

The Second Stage

But the next stage is the really difficult one, and the procedure to carry it forward is as diverse as industry itself. I want to study this second stage, for as we all know it is here that the success of our industrial research effort often falls down. We shall do well to enumerate some of the causes of this breakdown :—

(1) The intrinsic difficulty of proving sufficiently definitely the practical soundness of our deductions amidst all the variables which can vitiate trials.

(2) The fact that at this stage we have to satisfy and often to work through the production personnel in the factory in our effort to show that we have achieved something useful.

(3) The serious expense usually involved in the process, no matter whether we are applying our results to the production plant itself or in a tryout unit.

(4) The reluctance of those responsible for the production plant to allow it to be interfered with, or, in any case, to tolerate the interference of amateurs in subjects they feel they know so much more about.

(5) Not infrequently the trouble has its origin in two or three causes operating simultaneously.

Of all the causes of frustration I believe the commonest to be the human element. It must be admitted that the psychological setting is not generally favourable. In England the staff and personnel who run factory plants are usually supreme in their own sphere and proud of their set up. It is only natural that they should be critical of those who come to propose changes or to indicate blemishes and prescribe remedies. Our research men not having yet proved their case, from a practical standpoint, but asking for facilities whereby they can prove it, convey the impression that their research work does not anyway give them entire confidence in their proposals. The production man thus sees several reasons why the research man should not seek to apply the results of his work, or should make his experiment in some different way and in many cases he has to be satisfied to be " thanked for his interesting work which shall receive consideration."

When this sort of atmosphere prevails it is not usually the fault of one side, and it would certainly be wrong to assume that the research view is always correct. For obvious reasons it is a serious matter to make experiments and to take chances with the processes and products of the production lines themselves. The production management whilst earnestly desiring progress dare not lightly over-ride the factory personnel whom they rightly hold responsible for the efficiency of production and the uniform quality of the product. We all know how easily these can be thrown out of gear and what a troublesome matter it is to restore them in all but the simplest cases.

It would seem, therefore, that a study is worth while of the practical experience of those associated with these tasks and the means which exist or which need to be created to meet the requirements of these transition problems.

In this connection the author will lead off mainly with his own experience. Amongst the products and applications from which this experience has been drawn are the following: Electric lamps—radio receiving and transmitting valves—special metals and alloys for high temperature operation in lamps and valves—glass—refractories for glass making—refractory components (alumina)—iron powder—selenium rectifiers—jewels for watches—diamond dies for wire drawing—quartz crystals for oscillators and amplifiers—radio electrical equipment of all kinds—heavy alloy (mainly tungsten)—hot-plates for cookers—electric heater elements—steam turbines—electric light fittings—telephone equipment—primary batteries—arc lamp carbons.

These products mostly concern separate factories or anyway different managements, but always the same research organisation. There should be, in this experience, a fair variety of conditions, but they are far from exhaustive.

Psychological Factors

The one common and invariable requirement—and the most vital—is a psychological condition favourable to co-operation and mutual confidence between all who are parties to the effort. This, of course, sounds platitudinous but it just does not happen without careful and patient preparation.

The progressing of new developments after the research stage is a functional activity which usually tends to cut across the regular structure of responsibilities in an organisation planned for production. A new development demands the enthusiastic interest therefore of a number of people in different departments and, later on, their active contributions to its progress.

We all know what a tax this puts upon goodwill and self-effacement. Thus those at high levels must contribute something more substantial than mere benevolent generalisations. Those below them need to be made conscious of active interest from above and a discrimination by their chiefs between the paying of mere lip service to collaboration and a determination on their part to surmount its inconveniences.

A great deal depends on the attitude of the research group, who will be unwise if they use the occasion to point the moral of "what we can do." They will do well to enlist the interest and support at an early stage of those on whose backing and help they will eventually depend, if the project goes forward.

The keeping of a thing under your hat until you are ready to let it burst upon surprised and sceptical colleagues is not normally good psychology.

If the research people show thus a correct attitude in seeking to prosecute their plans, the staff of the production side of the organisation should give them all advice and encouragement to have a good run for their money. This may involve a good deal of sacrifice and perhaps compromising the future by following unattractive paths; but it is no use fighting a rearguard-action against inconvenient progress. If it is a good thing, some organisation in the world will follow it up sooner or later.

The commonest and most difficult issue to decide is the plea that whilst a new proposal may be good and promising, its ultimate importance is not so great as that of alternative claimants for the available facilities. This is no place to try to decide such questions: They must be considered on their merits—always remembering that even though a scheme is carried a certain distance only to be discarded, much is learned which is of permanent value from the efforts put into experimental work.

Production plant items in the Laboratories

In cases where the product or process or the component of an assembly to be studied is not too bulky, it is always practicable to have in the laboratories replicas of the production tools and methods. These can often be used to assist in making early rough trials; or alterations can be made in them in order to test out innovations. For instance, in the study of the powder metallurgy process of metal making, a relatively small laboratory can accommodate the powder reduction process—press for ingot making—sintering ovens—swaging equipment and wire drawing. Without these we should have had to give over any idea of studying improvements in tungsten wire quality and characteristics.

The same may be said to apply to electric lamps, jewels, diamond dies, primary batteries, and the like. Such equipment in the laboratory not only serves the above purpose but its use by the research staff makes them personally familiar with the factory equipment—sometimes more familiar than the factory supervising staff, who are not always in the habit of sitting down and working the production machines themselves.

Most metallurgical processes, of course, are studied in a preliminary way on laboratory equipment of some sort and individual parts of processes—for instance, wire coiling for lamp filaments, tool design for machining intricate components or components made from special materials—are brought to the laboratory for experimental examination.

But the author regards all these as concerned with the first (laboratory) stage. Although they help the research man to a state of confidence or otherwise in his conclusions and give him an idea of the difficulties in making them practical, they are a very long way from establishing the process from the points of view of reliability, uniformity and economy—to mention only three aspects vital for success. Something much nearer production conditions must be attempted before anyone can claim that the innovation is ready for the production line.

Responsibility for second stage

If the innovation is very novel or problematical, it is the author's experience that it is best tried out through the next stage under the auspices of the research staff, whether the actual scene of the "try out" be the factory or the laboratory. As parents of the new idea the research staff are likely to concentrate the maximum of determination and facilities into making it successful. But through all its

vicissitudes the factory staff should give advice and guidance and all practical help they can, for ultimately the child will be theirs to make or mar.

But there are cases in which the main responsibility for Stage 2 is by agreement taken, from the first, by the factory technical personnel, the research staff being then consultants and helpers.

Here we must consider frankly the position of the Works Laboratory and its staff—often a delicate and contentious subject where a Research Laboratory has come recently on to the scene. According to the way its functions are defined and are carried out, the Works Laboratory may be the greatest help or the most depressing kind of hindrance in the processes we are considering.

Sometimes the Works Laboratory is a semi-detached entity which, in addition to a multitude of other functions, seeks to take over the half-proved or half-developed ideas from the research staff with a view to their further development and their application to production. As such it is liable to become the cemetery of many a good proposal, through interposing itself between the research man and the production engineering staff from whom the former should acquire, by direct contact, his knowledge and experience of the production industry which he is seeking to serve. To introduce an irrelevancy—it is the author's experience that factory managements often underrate the importance of pressing upon the research staff (a) the opportunity of educating themselves in the industry by intimate association with its processes (b) the stimulation of new ideas which comes automatically from such intimacy.

If the personnel of the works laboratory either come under the Director of the Research Laboratories or are part and parcel of the factory engineering staff, the above disadvantages are much less likely to prevail because, in a new development, the works laboratory personnel either act with the research staff or with the production engineering staff and cannot be interposed as a " development link," preventing the research staff from having full tether in establishing, to the reasonable satisfaction of all concerned, the soundness or otherwise of their own proposals.

The "try-out" unit and the pilot plant

Wherever it can be managed the policy of the regular try-out unit is, in the author's experience, the proper one if it is desired to prosecute development programmes with energy and speed. The unit is sometimes designated a pilot plant, but I conceive this term to

apply to a small production plant designed to run continuously with the object rather of producing a product than of proving practicability. The term "pre-production" is sometimes used to denote the process of running a pilot plant; a try-out unit could easily develop into a pilot plant pre-producing in order to obtain experience with the product.

May the author now give particulars of some recent try-out and pre-production experience at his own establishment?

During the war the need for maximum speed in development of new devices and products, together with the greatest measure of certainty in their quality and of flexibility in modification of design, caused us to add greatly to our try-out facilities and to establish within the domain of the research laboratories some 20 try-out groups for new products, most of which, under war demands, had very soon to undertake pre-production on a considerable scale. The try-out period for a new product varied from about nine to eighteen months, according to the luck (or foresight) in surmounting teething troubles and in anticipating modifications needed by the users. When this was succeeded by routine pre-production the latter period may have lasted a further one to two years.

Some of these try-out groups have been engaged on the fabrication of Radar valves, with the cost per valve varying between about £1 to £10.

Experience has shown that where there are many operations, and the finished article is subjected to tests embracing many performance characteristics, a minimum production rate of about 100 per week is required if rapid and reliable technical statistics are to be obtained.

The examples now under consideration usually entailed 25-35 operators making about 200 articles per week, each group being headed by a capable physicist, engineer or chemist with a junior assistant. In technical matters the try-out group generally leaned upon the research group which had originated the product and which had ultimate responsibility for its technical success and type testing. The try-out group leader was not expected to do more than use his professional skill to organise intelligently the processes or constructions evolved by the research group, although in fact he usually did much more than this.

He had at his command the services of the mechanical engineering department of the laboratories, for co-operation in designing and making tools and components. Where glass was involved in the design they utilised the service of the experienced laboratory glass workers.

The rule was usually to have only one type of product at a time per try-out group, so that singleness of purpose might secure concentration of attention upon the perfection of the selected product.

The try-out groups were generally located sufficiently close to the particular laboratory where the research men worked, to enable them to attend to their share of the effort without undue interference with their current research work.

The running of such groups required for each one a planned system of component and material supplies, of testing, inspection and dispatch of the product (carried out under a separate group), and also a sufficiently complete but simple costing system.

However carefully the initial design of the article and the try-out tools are carried out, the early stages of performing repetition operations usually show up manufacturing weaknesses either of a mechanical or technical nature. With the product we are considering, a rate of 100 per week or more ensures continuity of the operations, and makes frequent statistical analysis of quality possible. This greatly facilitates the tracking of causes of high operational losses or undue spread in characteristics of the completed article.

When the rate of production is small it is very easy to under-rate the seriousness of a fault, and correspondingly difficult to assess improvement, but with a group of the size quoted the leader can keep in intimate contact with the various operations and thus be in a good position to link the statistical data with operational weaknesses.

It is desirable that the personnel engaged on the operations of the try-out unit should be of a rather higher grade than that which is normal for factory production, for presumably new techniques are involved. The stress in a try-out group should be much more on quality than speed, although the latter is one of the factors used in assessing the suitability of any given technique or machine. The balance between quality and speed comes at a later stage when a reliable quality level has been achieved with which to compare the factory product.

The method of payment also needs consideration. Piece rates for a try-out unit are usually out of the question because a given operation is not likely to be in use for a sufficient time, and piece rates are liable to accentuate quantity rather than quality. Even a bonus scheme on good output is difficult to operate as there are necessarily many technical difficulties outside the operator's control. The author's experience has been that a weekly wage, with suitable increments to award merit, is the only satisfactory method of payment if conscientious and careful personnel have been chosen.

If the new product which is being tried out uses existing techniques, a fairly rapid improvement in manufacturing shrinkage may be expected and six months is likely to be a sufficient time in which to attain a reasonable efficiency of production. If on the other hand, the new product incorporates many novel features of design and technique, twelve months or longer elapses before one can be reasonably certain that no new major technical problem is likely to arise.

It may be only after making 1,000 or more sound specimens under reasonably constant conditions that a real measure of the spread of technical characteristics of the finished article can be obtained and a reliable tentative specification drawn up. Should the functions of operation impose stringent limits on any special characteristic a considerable portion of the time taken to achieve a steady production efficiency may be used in attaining the degree of control which this necessitates.

Since the purpose of the try-out ought to be achieved in about the first twelve months, the average cost during this period of the article made may be somewhat more than double the subsequent factory cost if transfer is made after this time.

A pre-production period following the try-out period gives several advantages both to the research and manufacturing organisations.

(1) The research and works personnel can gain early experience of those defects which only show up with quantity production, and gain a much greater insight into factory difficulties. Minor changes in design sometimes greatly facilitate later production.

(2) The opportunity to study operational sequences, etc., which give a valuable background for future design and research.

(3) The works technical staff can see and profit by the earlier errors, and when the manufacture is introduced into factory production a start can be made with the minimum of teething troubles and inefficient production.

If the factory engineering and production personnel have been fully consulted during this try-out stage and have taken every opportunity to study its running and economics, it is unusual for there to be any difference of opinion as to whether or no the result is successful enough to justify adoption by the factory.

If the factory decides to adopt it their staff will probably make innovations based upon their appraisement of the working of the try-out unit. For this reason it is often desirable for the try-out unit to keep running on pre-production in order to cross check with the factory when its product begins to come through. It has been found

that within three or four months of starting works production the cost per article was already of the same order as the final pre-production cost.

Overall costs of try-out units

The regular try-out unit is nearly always run in conjunction with an industrial undertaking, and its effectiveness from a financial standpoint is to be assessed by comparing it with the plan of introducing the new product direct into the factory production system. In any such comparison the output—or some of it—in both cases can be reckoned as saleable and the receipts from what is sold are a set off against the costs. The sale of the product may cover say 50% of the cost of the try-out group over the first year.

It is sometimes proposed, however, to run such units under independent conditions, that is to say, unconnected with an industrial concern, for instance, by Research Associations. Whether a Research Association can do this effectively naturally depends on the circumstances of each case. There are obviously several less thorough-going methods of procedure than that of the self-contained try-out groups I have been describing. But whatever is done the probable cost has to be appreciated.

A group of 30 operators can hardly cost less than £150 a week. Add 150% overheads (a minimum allowance—it could easily be double this) to cover establishment charges, services of ordering and costing department or mechanical engineering services, and we have over £400 per week without reckoning costs of materials. A group must work steadily as a team and usually be kept working even though the product for the time being is useless. Everyone who has experience of this kind of thing will appreciate the reasons for establishing and maintaining a steady routine of operations.

Six months is a short time for establishing a new product if at all tricky, so no matter how we try to pare down the above estimate we may assume the minimum running cost of establishing a pilot plant on a new product to be of the order of £10,000 per six months when (a) the product cannot be sold and (b) when the cost of the disorganisation of the main production plant (had the product been introduced there) cannot be reckoned as an offset. Where serious capital expenditure on plant is involved and expensive materials or components used, these must be added. If the product is at all bulky its storage sometimes becomes a problem.

To sum up therefore—whilst the author strongly commends the use of the try-out unit as the intermediate step for transferring research results to production, he would warn those who have so far no experience, that each scheme should be planned and realised in advance in all its aspects before deciding if it is worth while and practicable in any particular case.

Experiments with full scale plant

When a research result concerns the operation of existing large scale plant it cannot usually be progressed through the medium of a try-out unit and every means has to be taken to establish the likelihood of success before taking any chances which might detrimentally affect the quality of the production product. Eventually, of course, the change is expected to work an improvement, but this is not always achieved without having first to put up with a period when wastage is heavy and expensive. The metallurgical and glass making industries are amongst those which would yield instances of this.

To give the innovation the best chance of success, the prior laboratory work must naturally be as complete and thorough as possible—much more so than would be necessary had a try-out unit been possible. In addition to this it is essential to establish a system of plotting the results of routine measurements and observations made at various stages in the manufacturing procedure as well as results of tests on samples of the end product.

The type of measurement to be made has to be determined by those most familiar with the plant and in many cases the agreed measurements may not differ appreciably from those normally made in the plant.

The regular plotting of such data on a time scale provides a running pictorial commentary of those features of the process or product deemed to be important. When some 20 to 50 points are plotted for any one of the observed quantities, methods are available by which the magnitude of the variability normally associated with the process can be estimated and suitable limits indicated on the chart which will show whether abnormal variations have existed or are developing.

If the plotted results do not indicate any abnormal variations, the process and/or end product quality may still entail too great wastage. In such a case, too great a variability is normally present in the process or the agreed routine measurements omit to give information about an important stage of the process.

It is in situations of this kind that the association of a research chemist, physicist or engineer with the technicians responsible for the plant can become a powerful aid to progress. The research man should be very familiar with processes concerned and should have a working knowledge of statistical methods, and I have already stressed how important it is that factory management shall provide a psychological environment which will encourage real comradeship between the research and factory personnel concerned.

As a consequence of a statistical study of the accumulated routine data, guided by knowledge of the process, it is often possible to identify or at least to obtain clues to the location in the plant or process of some of the principal contributions to variability, and thereby to concentrate technical attention where it is most likely to yield the desired results.

It will be clear the important role the Control Charts play whenever an agreed modification to the plant or process is made. They provide information at the earliest moment of the effect of such modification and also factual evidence on which to base decisions.

In complicated manufacturing enterprises involving a number of widely different techniques under the control of different technicians, we have all noticed how frequently difficulties are " due to the other fellow " and the art of " passing the buck " sometimes appears a greater asset than real technical understanding.

The use of " Control " Charts, implemented by the kind of planned investigation which we are considering, tends to clear away some of the undergrowth of tradition, impression and misconception which prevents a clear technical view.

Sometimes some of these steps in the manufacturing processes which have been accepted as contributing to particular difficulties or to govern particular qualities of the end product, will be found to be of much less importance than others whose influence had scarcely been suspected.

RELATION BETWEEN COSTS AND PRODUCTION RATE FOR A TYPICAL "TRY-OUT UNIT"

CHART I

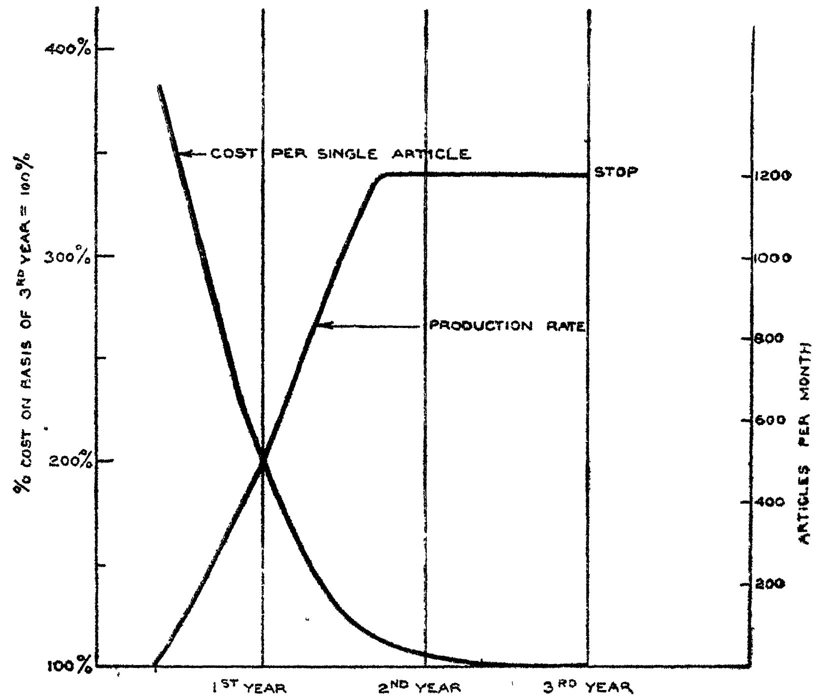

Chart 1 shows the rate of output and costs for a group of about 35 people making one type of electronic article and reaching a maximum rate of about 300 a week. The costs were taken at the end of each financial year and the first period covered the initial expenditure on tools and special equipment. It will be noted that the cost per article of the first period of about 7-8 months is about double that of the second period of 12 months, and thereafter increasing efficiency of operation gave a further decrease in cost. This ratio of costs with time was fairly typical of other groups, although they were making articles differing widely in design and actual cost.

CHARTS II AND III ILLUSTRATE RATES OF GROWTH OF PRODUCT AND COSTS

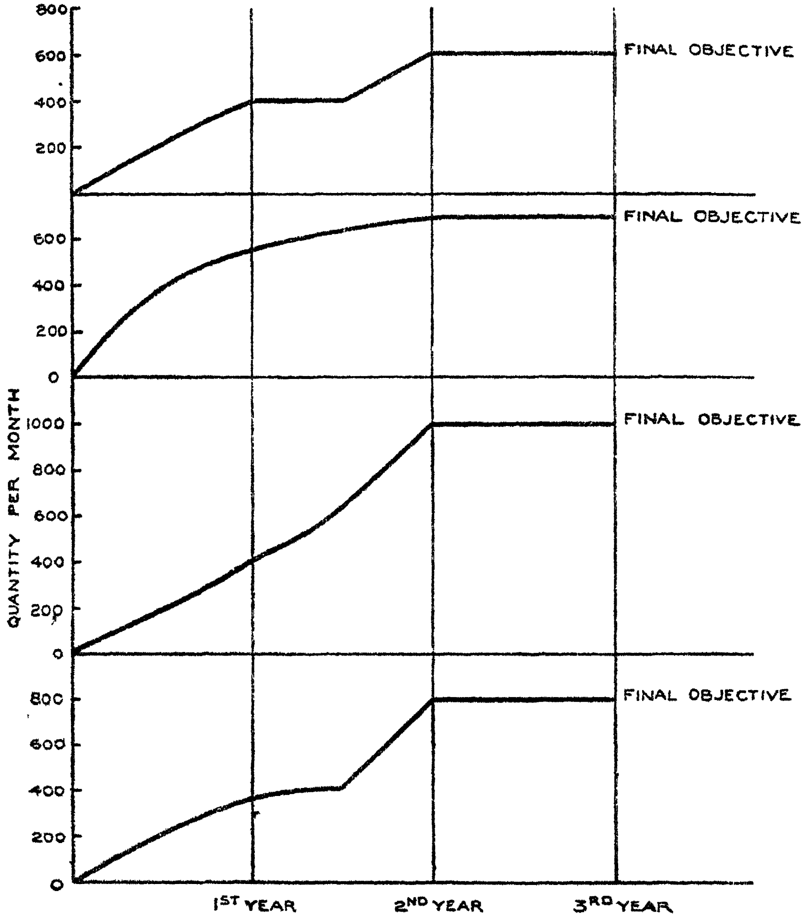

CHART II

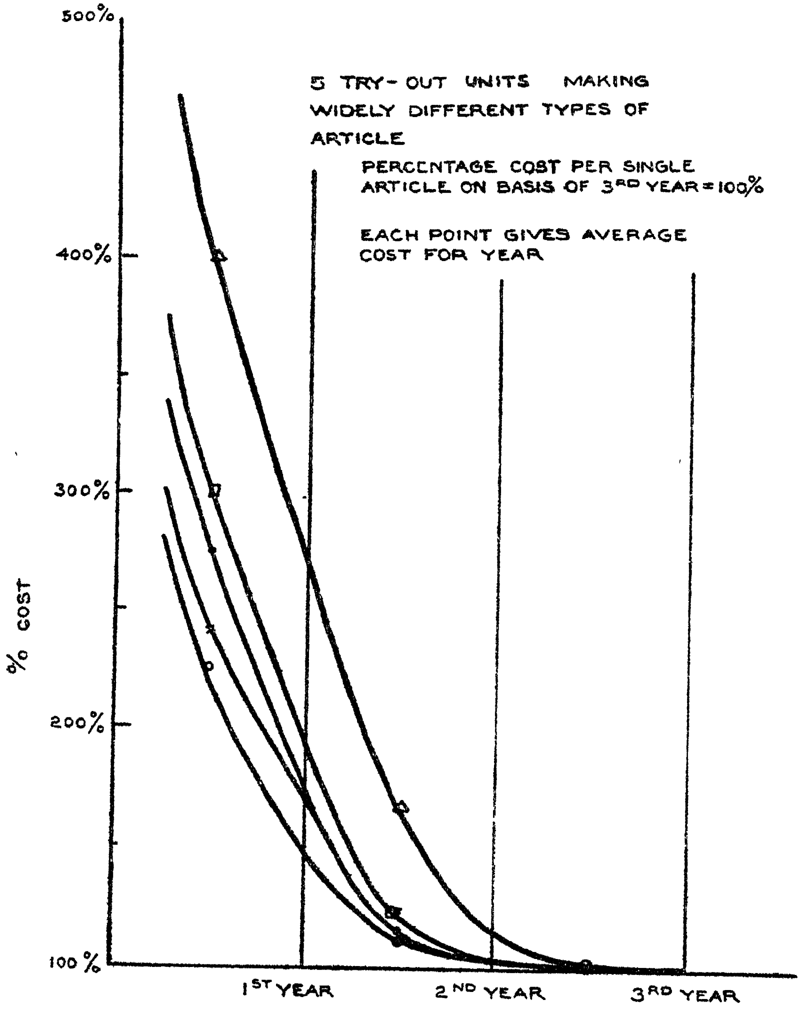
500%
400%
300%
200%
100%
% COST
5 TRY-OUT UNITS MAKING
WIDELY DIFFERENT TYPES OF
ARTICLE
PERCENTAGE COST PER SINGLE
ARTICLE ON BASIS OF 3RD YEAR = 100%
EACH POINT GIVES AVERAGE
COST FOR YEAR
1ST YEAR
2ND YEAR
3RD YEAR

CHART III

SESSION II

Scientific Research and Production

DISCUSSION

"The Need for 'Research Interpreters' in Industry"

SIR WILLIAM T. GRIFFITHS (President of the Institute of Metals, Chairman of the Mond Nickel Co. Ltd.) said that the subject before the Conference that afternoon, "Scientific Research and Production", lent itself to lengthy discussion, but in view of the time limitation he would confine his remarks to just one or two points.

It seemed to him that the problem of getting the results of research in the laboratory used promptly in the factory tended to become greater rather than less. As our technique of research became more fundamental, and as our production methods became more intricate, the requirements in the way of staff became more and more specialised. Further, as we learnt more about the details of processes or products, taking a further step forward in knowledge required an increasingly fundamental approach.

As has been indicated in the papers that afternoon, the human element entered largely into this problem. The "practical" plant manager often had difficulty in understanding the research man's language and approach to a work's difficulty, while many research workers found it hard to appreciate the primary wants of the plant, and to explain the implications of the results of their work in development of plant processes.

It was his opinion that the extent of the difficulty should be recognised and steps taken specially to select and train suitable staff for bridging the gap between research, laboratory and plant. Individuals with special attributes were required. They must have suitable personality, they must have sufficient knowledge of fundamentals and research method to appreciate the research workers' outlook, and must have adequate experience in production technique and requirements to know what the plant needed. They would, of course, need ability in exposition so that they could define the plant problem to the laboratory and explain the research results to the works' personnel. Relatively early selection would be advantageous and Universities or Technical Colleges and Industry would need to co-operate in the training.

This type of individual would certainly be of value in large concerns. He would be of even greater value as the size of firms became smaller.

This was particularly the case where, on account of magnitude or type of production, " pilot " or " pre-production " plants were impossible and proposals from the research laboratory had to be tried out in the production unit itself. Process personnel had to be persuaded that production interruption was justified and their interest and co-operation maintained in spite of the not infrequent initial disappointments.

The availability of the " Research Interpreter " or " Development Officer " became of greatest importance when the size of the concern or organisation became so small that a research laboratory was not justified. It was suggested that in the case cited by Mr. Healey. where but £2,000 per annum was available, what was wanted was not " a research worker or two " but a suitably experienced " Research Interpreter " able to apply the scientific knowledge provided from outside.

In these last cases the industry's Research Association could be of particular value. Research Associations not only carried out research but kept in touch with research activities throughout the world. Contact with them by a firm's Development Officer would help greatly in that firm benefiting from the growth of scientific knowledge.

Finally, in order that the results of scientific research should be used promptly and to the best advantage in Production as well as other sections of industry, the speaker thought it important that the highest executive positions in industry should be open to suitable men with scientific training and he suggested that from among men selected and trained for the purpose here discussed would be likely to be found those suitable for these posts in industrial administration.

"Science and the Building Industry"

MR. T. G. W. BOXALL (of the London Brick Company Ltd.) said that the building industry was in an unusual position in regard to the interpretation and application of research results, inasmuch as it consisted of a very large number of units varying in size from firms employing several thousand operatives to firms employing a very small number, and also embraced several professions and a wide variety of trades. Raw materials were employed in widely different circumstances.

The Building Research Station of the D.S.I.R. had largely concentrated on the investigation and study of building materials, although more recently it had undertaken a wider sphere of work including sociological studies. The building industry itself attached great importance to research; several large concerns were setting up research departments of their own, and others were keeping in closest touch with the latest developments of building material manufacturers and of the possibilities of employing scientific methods.

So far as brickmaking, one of the oldest industries of the world, was concerned, science was required to help it retain its original lead, not only by improving methods of manufacture but through education so that the workers would take a greater interest in the scientific side of production.

"Filtration Engineering"

MR. VOKES (of Vokes, Ltd.) said he doubted whether any industry had gained more from scientific and technical research than had the filtration engineering industry, which when the war broke out had proved of paramount importance. During the war British filtration equipment had been found to be five times as efficient in performance as the enemy's. Scientific research was essential in this field, which included the working atmosphere in mills, factories and mines. If workers could be assured they were going to breathe a dust-free atmosphere it should be easier to get them to return to "difficult" industries.

It was particularly important to-day that local councils should be aware of what modern industry required locally, and should be willing to assist wherever practicable.

"Thermal Engineering Research"

MR. G. N. CRITCHLEY (Director of Thermal Engineering, Ministry of Supply) referred to the pressing need for extended and organised research in the field of thermal engineering in order to evolve industrial processes capable of producing manufactured goods with the lowest possible consumption of fuel.

Following diligent research, the fuel consumption of glass-melting furnaces had recently been reduced by about 12 per cent. by insulating their roofs, and the insulation was yielding a total return of over 4,000 per cent. on the capital invested. It had not yet proved

possible to insulate the roofs of British open hearth steel-melting furnaces, although if this could be achieved corresponding savings would result.

Again nearly 30 per cent. of the potential heat of producer coal was lost in the process of converting it into producer gas. If research could evolve plants capable of generating the same amount of producer gas from 10 per cent. less coal, the value of the coal saved would 'write off' the value of the replaced plants in approximately eighteen months.

Official information as to the quantities and types of fuel which would be available to industry in the future was urgently needed, as was a comprehensive plan of research to be carried out in the field of thermal engineering. He recommended that some organisation be set up to plan this research work, and considered that the F.B.I. might be best placed to undertake the task, which could play a key part in restoring national prosperity.

"Inventions"

Mr. A. Saunders (of Saunders Tool Co. Ltd.) referred to the importance of inventions which were the basis of all industry, and stated that the machinery for enlightening inventors was inadequate. He thought also that universal protection throughout the world should be given to any British patent which was marketed in this country. It was most important that all ideas that came forward that might help industry and the people, should be encouraged and facilitated both by the Government and by industry.

"Quality is Relative"

Mr. W. C. Spowart (of Perrite Ltd.), as a business man charged with the direction of a small industrial firm, pointed out that quality was relative and in the final analysis depended on what the customer was able to pay. Great Britain in the past had sold the finest quality goods in the world, but they were sometimes too expensive for overseas customers.

Equally production of an extremely long-lived machine, even though of the finest quality, was not always sensible. Especially when trade conditions were not good it was necessary to produce what overseas people could afford to pay. It should be remembered therefore how research could assist the sales organisation. It was necessary for the research and sales departments to keep in the closest touch with

one another, so that people would be sold what they wanted, at the price they could afford at the time.

"Building Licences and Priorities"

Dr. C. J. Smithells (Director of Research, British Aluminium Co. Ltd.), said that the great stumbling block in the development of research in industry to-day was accommodation. In his own Company's case an Elizabethan mansion with stables and outbuildings had been converted and was now being employed as temporary laboratories, but so far it had not been possible to obtain a licence to build proper laboratories. Up to date there had been no Government pronouncement of policy with regard to building licences for research establishments.

He asked the Government to announce its plans as to what proportion of the building facilities of the country were to be placed at the disposal of industrial research and research generally, so that research programmes for the next few years could be planned ahead.

"The Psychological Handicap"

Mr. J. Valentine Backes, (of Ch. Goldrei, Foucard & Son, Ltd.,) said one of the reasons for the weakness of the application of science in smaller units of industry was fear—fear of loss of prestige, loss of status, and even loss of livelihood among the individual members of the concern.

A foreman's position, for example, may be due to the fact that he has been in the industry longer than the rest of the staff, and consequently his status was dependent on his experience. But when a new process comes along this superiority was lost, and fear of loss of status develops a non-co-operative attitude.

Again, many scientific ideas tend towards economy—the labour mind at once fears loss of employment by the proposed saving of labour. This develops a sense of frustration and subsequent non-co-operation with the new idea.

It is very important, therefore, that efforts are made to convince all engaged in industry that they can and will become partners in the success of, rather than losers by, scientific application. To this end a study of the psychological approach and the putting over of science to the industrial staff was of the greatest importance—in fact as im-

portant as the scientific discovery itself if the benefits of science were to become practical industrial possibilities. Failure to appreciate and apply psychology is the greatest handicap to the science of to-day becoming the industry of to-morrow.

"Consumer Research"

CAPTAIN R. T. DENT (of British Typewriters, Ltd.), said that not enough consumer research was undertaken. Articles produced for general use were sometimes not entirely suitable for the purpose for which they were intended. He suggested that scientists should be encouraged to investigate closely to determine precisely what was required before production started.

"The Viewpoint of the Practical Man"

MR. B. H. DYSON (of Hoover Ltd.) spoke as a Works Manager who had received considerable assistance from his Company's own Research Department. He commented on the gap that can so often exist between the research section and the production drawing board. The production man invariably has to interpret from a drawing what was in the mind of the research worker.

It was also important to have recognised channels through which the people in research, development and production sections could get together during the development and design stage. This was particularly true in view of the fact that often a decision had to be made to freeze the design and to get on with the production job.

Considerable success with the introduction of new projects had been achieved in his works by having laboratory and production staffs working side by side until the product was ready for full production, and this definitely shortened the period from the design to the production stage.

The problem of "styling" (design and colour) should be brought in at the early stage of new developments, in order that those methods of manufacturing that lend themselves to this important aspect were given full consideration.

Possibly the greatest achievement was to get the people of the various sections not only in the same building, but working together to achieve something in common and not working in water-tight departments.

"Porosity in Iron Castings" (*Communicated*)

MR. T. E. PARKINSON (Secretary of the Council of Ironfoundry Associations). The Council of Ironfoundry Associations is interested in the manufacture of iron castings of all types, and while recognising that the method of filling castings withstanding high pressures to overcome any porosity, referred to by Dr. Hosking (see page 31) served its purpose during the war period, it is desired to point out that under normal conditions such a practice will not be expected to be necessary. Furthermore the procedure mentioned is not, as might have been understood, applicable to general foundry practice or to their products.

The Cast Iron Pipe section of the Ironfoundry Industry produces approximately 500,000 tons of cast iron pipes per annum, the Automobile Casting section another 100,000 tons, the Boiler and Radiation section 75,000 tons, and malleable tube fittings and cast iron flushing cisterns 15,000 tons. All of these, by nature of the conditions under which they are designed, must be free from porosity, and they are all tested in the light of the service for which they are required to operate. The results of these tests demonstrate that the number of rejections on account of porosity is infinitesimal.

It is only desired to place this question of porosity in its correct perspective.

SESSION II

Scientific Research and Production

ADDRESS BY THE CHAIRMAN

THE RIGHT HON. JOHN WILMOT, J.P., M.P.,

Minister of Supply.

I am sure that the debt which the people of this country owe to scientific research and development, particularly during the war years, is still not appreciated at its full value. I believe that the important part that scientific research and development can play in the development of British industry in the immediate future and in the years to come, is also not fully appreciated. I am preaching here to the converted in this matter, but I hope that my remarks will reach a wider audience, and that the papers which are being read at this conference will also reach that wider audience. For upon the response which the mass of British industrialists make to the tremendous opportunities offered to them by the science depends our industrial future.

To go back a little in history, to those dark days of the war period, when the overall strategic conception—to use a phrase currently popular—was that we should never hope to beat the Germans by weight of numbers, our only hope lay in having a better equipped army, navy and air force: better equipped with weapons and with the innumerable scientific devices which go to make up the modern army in the field, better equipped in medical services, better equipped in personal gear and better equipped psychologically because of the superiority of its munitions. David defeated Goliath because he had a better weapon than the physical might and size of the giant. The Roman legions frequently won their battles in the face of vastly superior odds because they had better weapons than their enemies. The better armed a man is, the more likely is he to defeat superior numbers. As events turned out, we were eventually able to number a considerable proportion of the big battalions on our side, but our scientific research was not wasted because it saved us hundreds of thousands of allied soldiers' lives. At almost every turn in the war science played its decisive part: in aircraft, in bombs, in radar and radio, in guns, in ammunition, in engineer equipment, in medical and

ood supplies. In almost all these fields, we were superior to the enemy. That superiority sprang, mainly, I think, from two causes: the first was that our scientists, man for man, were better than those of the enemy; secondly, they were free men and not a regimented horde. It is one of the interesting things of the war period that we did not hear the names of very many British scientists as inventors of this or that. Many attempts were made to fasten great inventions upon individuals, but they nearly all failed because individuals were rarely responsible for the major inventions of the war. There was a perfectly valid reason for that. Instead of asking one man to design a new aircraft or engine or gun or radar set, we gave that work to teams of scientists and set those teams to work on various aspects of the one large problem. The result was that we had the best work of thousands of brains. I suppose that most spectacular British achievement during the war was the conception, design and construction of the Mulberry Harbour, yet none of the men associated with it would claim to have "invented" it. Hundreds played their part in it and were content to play that part. They did not seek the glory of a spectacular personal achievement.

Because of this stress on teamwork, there is an impression in some other countries that British scientists are not as good as their own. The results of our wartime work show that that is completely false. Our scientists individually are as good as or better than any others in the world and given the opportunity they will prove that they can play a very big part in the industrial life of this nation in peace as in war. We must never forget the lessons of the war. We must continue our research and development in teams and with the team spirit. Given that, the scientists can produce the results, but there must be a greater acceptance of these results by industrialists. They must be prepared to scrap outmoded processes and machinery and equipment. They must be alive to the need for change and for adaptation to make use of the developments offered to them. Almost every nation in the world is becoming industrialised. It was easy for Britain to lead the world in industry when Britain was the only industrialised country. It will not be so easy for us to lead in the future when there will be such severe competition to face from other nations. But if we use our scientists and research workers as we used them during the war, we can keep ourselves ahead in the race for ever greater and cheaper production of consumer goods. We can help to make the life of the ordinary man richer and fuller by that increased production. Scientific research and development can help us to reduce hours of work, to increased and more fruitful leisure, to easier and speedier travel. And that leisure and travel will render possible a

better understanding of the problems of this world and a better understanding of our neighbours.

The addresses that have been delivered this afternoon have given a very clear indication of the amount of scientific knowledge that is available on every aspect of the problem under discussion. A thought that occurs to me arising from the first of these papers is the value of Quality Control in industry. This country has a reputation in overseas markets for products of first-class quality and reliability. We must do everything in our power to keep that reputation and one of the methods to help to that end is Quality Control. It was extensively used in the Royal Ordnance Factories by the Ministry of Supply during the war. It sprang directly from the application of scientific methods. It saved us not only thousands of man hours and large quantities of material, it also saved us the heartache to the worker in finding that the product upon which he had been working was finally thrown away as scrap. This is because Quality Control rejects scrap material at the point at which it becomes scrap and does not permit it to go on until it becomes a worthless finished article.

It may be thought that I have neglected the smaller factory in what I have said and that I have been talking only about the larger organisations, who are able to support research and development on a considerable scale. I am sure that numbers of smaller factories and, for that matter, smaller industries, are anxious to organise co-operative activities of this kind. There is a means by which this can be done. Under a recent regulation arrangements can be made after consultation with the representatives of any industry, for providing services for technical and market research for the collection of information and statistics and any other services conducive to increased efficiency in manufacture and marketing the products of that industry. Provision is made for these services to be financed by a statutory levy upon the industry. This means that everyone in the industry will share in the cost and in the benefits of that research and it should not be thought that the initiative in making use of the powers which the Regulations confers can spring only from the Government. If any industry feels that it might benefit from arrangements of this kind, I would urge it with all the emphasis at my command, to approach the Board of Trade with its own proposals, to see what help can be given to putting them into effect.

There is scope for improvement in the means by which the results of industrial research are spread abroad. There is, of course, the Technical and Trade Press which performs a most valuable service. There is also the Department of Scientific and Industrial Research which runs a very comprehensive information service both through its

headquarters and through its research establishments. But it is one thing to provide a service and quite another to get people to make full use of it. The remedy is in your own hands and in the hands of the industrialists of Great Britain; encourage scientific research and development by all the means in your power; encourage your own scientific workers and your own technicians to study the results of other people's research work; make use of that research work in your own factories; have the courage to scrap obsolete methods and machinery. In other times, this might have been a hard doctrine. In view of the shortage of labour which appears likely to continue for years to come I have every confidence that we can ask you to make these changes, not only without causing hardship—in fact, actually bringing substantial benefits to—the mass of the people of Britain.

As you know, I am, at least until the end of this month, a double-headed Minister. I am Minister of Supply and of Aircraft Production. I know you will be interested to learn something of our intentions that have been made for the continuation of scientific research in the joint Ministries when they are finally merged. We attach the very greatest importance to scientific research and we are retaining a staff of high quality to carry on with that work. The staff will not be so large as it was during the war, but that is because we must release a number of men to go back to the universities, to continue the teaching of fundamental research and to go back to industry. Both the universities and industry have been starved of scientists during the war years and it is absolutely vital that we should release as many as possible. That we are doing.

We shall see that as much as possible of the work achieved by these men will be made public for use by other research workers and by industry. I believe that that will be of the very greatest value. If I may repeat what I said earlier, I beg you to make use of it.

SESSION III

SCIENTIFIC RESEARCH AND INDUSTRIAL EXPANSION

ADDRESS BY THE CHAIRMAN

THE RIGHT HON. HERBERT MORRISON, M.P.,

Lord President of the Council.

The organizers of this Conference are to be congratulated on the choice of subject for this session. Industrial expansion is one of the most important problems facing the nation to-day, and it is a very satisfactory sign of the times that so many industrialists should have gathered together to discuss the relationship of scientific research to this question.

Industrial expansion is perhaps more essential to the country now than it ever was before. It is not a case of a single firm expanding its operations and reaping the benefit of its enterprise with increased profits. The welfare and possible survival of the nation as a first-class power depends upon the expansion of the whole of our industry. It is to expansion that we must look, firstly, for the means of getting necessary imports by increasing our exports; secondly, as the most rapid means of the desirable escape from the period of austerity, which no nation which has been exposed to the ravages of world war can hope to avoid; and thirdly, industrial expansion is essential if we are to carry through and support successfully the extension of our social services, the necessity for which everyone, save an insignificant minority, accepts. It is quite certain that without the aid of science no real and permanent expansion of industry is possible.

In the war we had to expand industry to make the weapons to resist aggression. We succeeded largely as a result of the close partnership between science and industry. Now we have to turn with equal vigour to the even greater problems of producing goods, firstly necessities, and then the so-called luxury articles, which, nevertheless, thanks to modern methods of production and transport, are within the reach of a growing proportion of the population. This demands the

continuation of the same partnership between science and industry which served us so well in war. The immediate task before us, with the world clamouring for goods of almost every variety, is to expand where we already know we can do so, since the new knowledge essential for producing new products must take time to accrue.

We need new factories; they must be economically built in accordance with the latest findings of building research. We must ensure the efficiency of those working in these factories. The factories must be lighted, heated and ventilated in the most modern manner, that is to say in the most scientific manner. Where necessary, scientific knowledge must also be applied in reducing unnecessary noise. How can we expect workers wearied with six years of strenuous effort in the war to continue to give their best unless we provide them, in their working hours, with the best conditions for health and efficiency that science alone can supply?

As you know in planning the expansion of industry we are paying particular attention to its location. Again here the help of science is necessary, and in particular, certain aspects of science for which the Department of Scientific and Industrial Research is responsible. A modern factory as often as not needs first a water supply, sometimes with special characteristics, amounting perhaps to over a million gallons a day. The Geological Survey is the organization which advises on this problem. On many occasions a project for an industrial expansion scheme in an area where it was particularly desired, would have had to be abandoned if the Survey had not been able to indicate a site where water of the right quality and of the necessary amount could be found.

Having got the water and used it, it has then to be got rid of. The disposal of these fouled waste waters presents no easy problem. We can no longer tolerate them being discharged into streams, converting them into little better than open sewers, as used to happen not so very long ago. Effluents which most of us would think are quite innocent are often by no means so in fact. Milk, for example, poured down a drain has a polluting effect 300 times greater than the same amount of domestic sewage. If a milk product factory discharged its waste without treatment into a river, all the fish would be killed and the river would be fouled and unusable for miles. This was a "headache" for the milk industry which the D.S.I.R. Laboratories have solved—a good example of Government enterprise beneficially co-operating with private enterprise. Let's have more of it!

Industry, endeavouring to expand in the conditions following a world war, is faced with many difficulties. Many materials are still in short supply and substitutes must be used. But perhaps the

greatest problem confronting industry during the transition period is shortage of man-power to operate the additional capacity resulting from expansion. One method by which science can help in solving this problem is by devising instruments to help in the mechanical control of industrial processes, thereby speeding up production, reducing wastage and saving labour. The method of quality control, developed during the war as a part of operational research, improved the quality of the product and sometimes released as much as 75 per cent. of the inspection staff to production. Increased mechanisation is mainly a question of design, but improved design is impossible without bringing into play the latest knowledge of materials, mechanism and engineering science generally. All these applications of science have the effect of setting free more workers from non-production to production employment.

The larger firms can look to their own research departments for the solution of their research problems, but a fully equipped and properly staffed research department costs a good deal of money and is beyond the resources of many of our smaller firms, which, except for their inability to carry out research themselves, are often extremely efficient. To these firms collaboration through co-operative research provides a solution for many of their difficulties. Practically all the main industries are, as you know, covered by Research Associations working in conjunction with D.S.I.R. and new Associations are steadily being created. I was glad to learn, for example, recently, that the Production Engineers and makers of Machine Tools have now formed a Research Association of considerable size, which the D.S.I.R. is backing very substantially—another joint effort of private and Government enterprise.

There is a factor which makes the pooling of knowledge and collaboration in research specially desirable at the present time. We are striving to win export markets and it is, therefore, the reputation of British goods as such which is important. One firm putting out inferior or ugly products may damage the market for our best firms. Good work for Britain is being done in this field by The Council of Industrial Design—exporters should let it help them.

I would urge every industrial firm seeking to expand its production to use every item of existing scientific and technical knowledge which will help it in its task. Much scientific knowledge of importance to industry exists in Government Departments and can be made available to those who seek it. Much has been collected from enemy countries, and furthermore the United States Government has recently expressed its readiness to exchange information with us. All this knowledge is at present rather scattered, and you may not know how

to set about seeking the bit you require. On this matter I can give some very simple advice. If you are in doubt, ask the Department of Scientific and Industrial Research to direct you to the right source. D.S.I.R. is at your service.

It would take a long time to catalogue the scientific and technical organisations which are either being conducted by the Government or being backed by the Government and which are at the service of industry.

There is, for example, the Advisory Service on Production Efficiency which, when it is fully developed, will put at the disposal of industry the most up-to-date technical knowledge which can be applied to securing maximum production and will make sure that the valuable lessons we learned during the war are not lost to industry in peace.

I might also mention the Institute of Management which in its early years will have the financial backing of the Government ; and in that connection the Committee which forwarded its recommendations to the Government was presided over by Sir Clive Baillieu, President of the F.B.I.

Another important and useful body is the Medical Research Council. Through their Industrial Health Research Board much important research has been done in problems of factory health, accident prevention, industrial diseases. A great store of knowledge is waiting there to be applied which, when it is, will add to the health, happiness and efficiency of British factories and workshops.

In Agriculture, the National Institute of Agricultural Engineering is a mine of information to manufacturers of agricultural machinery.

These are only typical branches of activity, all of which are giving constant and willing help to all kinds of industry. Through the D.S.I.R. it is simple to put an industry in touch with the research bodies whose work can be applied to its special problems.

Although we must rely on existing knowledge to meet our immediate problems, future progress depends on using new knowledge springing from research not yet started or still in its early stages. This fundamental research provides the reservoir upon which applied research draws. The reservoir needs to be replenished because in many fields little fundamental work was carried out in the war years. One of our first tasks, if industry is to continue to expand, is to see that adequate means are available for replenishing this reservoir. That means financial assistance and the provision of personnel for research at the Universities. Not only are they the main source of ideas which can be developed into new processes, new materials and even new

industries, but they are the training ground of the scientific man-power which industry so badly needs. It does not matter how well we organize research, or how much money we devote to it, the results finally depend on the enthusiasm, brains and skill of our research workers. We cannot afford to lose any budding scientific genius for lack of training, and we must therefore see to it that the need for well qualified University teachers is filled as far as possible, even if it means temporarily depriving industry of some skilled scientists.

There is one thing I am quite sure subsequent speakers will say, and that is that new industries and new processes do not spring up ready made overnight. Like a rising standard of life, they have to be worked for. They come from the seizing of opportunities for developing ideas originating mainly in the laboratories of the fundamental research workers.

As far as industrial research is concerned, research not applied is just so much wasted effort. As a nation we have been accused of being too slow in developing new ideas. Things have never been as black as they were painted, but we cannot risk being slow in the future. Therefore the first thing to do is to find out the reason for our past failures. One thing I am sure of is that the cause is not any fundamental inability on the part of our scientists to carry out applied research. Our war record has disproved this beyond doubt. The trouble lies elsewhere. Maybe it is due to national cautiousness, the characteristic which has had so much to do with giving stability to British commerce, and has made us so pre-eminent in banking and insurance. Maybe it is the innate thrift in our race which makes us want to hang on to things before we discard them, lest a penny of their value should be wasted. Maybe the British people are not very willing to try out new ideas and to accept new things ; but whatever the cause we must be bold in venturing in the technical field in the future, if we are to hold our own with our competitors.

The Government is ready to give every possible support to the promotion of research and its rapid translation into industrial practice. With regard to money industrial research is assisted by the exemption from Income Tax of all expenditure on research, both capital and running. Increased resources have been placed at the disposal of the University Grants Committee to help in the education and training of scientific personnel. Similarly the amounts available as grants to post-graduate students have been increased. Thus Government is encouraging industry to increase its expenditure in research and is doing its best to provide an ample supply of trained scientists to do the job.

So during this period of industrial expansion, so vital to the survival of the nation, we must use science in every way that it can possibly help. Let the scientific method of investigation be brought to the study of the stages which have to be gone through in carrying out the re-equipment of industry, to the study of the factors which delay the introduction of new processes and of the means by which high quality of output can be maintained. Let us employ men who, by their training, can explain not only the technical but the economic potentalities of a scientific discovery or development and employ them in positions where they are able to influence policy. Finally, let there be first-rate marketing research, guided by the methods of statistical science which proved so fruitful in what, during the war, was called operational research.

In this way industry will be equipped at all points to expand rapidly and fruitfully. Every advantage of new discoveries will be taken at short notice. What the customer really wants, whether at home or overseas, will be known and designs can be modified accordingly. And every bit of scientific and technical knowledge can be used in producing the new designs.

If industry can thus equip itself, the future can, in my opinion, be faced with complete confidence. Our industry will be able to hold the place which our scientific and technical skill entitle it to hold, not merely for the sake of individual profit, but for the benefit of the whole nation.

SESSION III

Scientific Research and Industrial Expansion

PAPER I

HOW NEW INDUSTRIES ARISE

By R. E. SLADE, D.Sc., M.C.,

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The present industrial system started in England about two hundred years ago. Up to this time Western European civilisation had progressed very little further than the older civilisations of Egypt, Babylon and Rome. But already some changes were taking place in Europe. The art of printing had appeared in the fifteenth century, and the development of navigation had led to increases of population in some European countries and in England. Then about the year 1700, new industries began to appear in the North Midlands, first slowly and then faster as each new industry led to another. It is easy to see how the different industries followed each other in a natural sequence.

The steam engine of Newcomen, invented about 1704, soon came into use for pumping water from coal mines, then Abraham Darby introduced the burning of coal instead of wood in making cast iron. (Dudley had tried to do this a hundred years before but he had been forced to desist by the other iron workers.) Darby's son invented the beehive coke-oven, Huntsman introduced crucible steel and Henry Cort started the rolling of puddled iron. By the middle of the eighteenth century England was exporting iron instead of importing it from Scandinavia and other countries. With iron available rapid developments took place in the cotton industry.

For thousands of years fibres had been spun into yarn and the yarn woven into cloth. Improvements had been made in the processes from time to time, but they brought little change to this cottage industry. But from 1750 there were remarkable developments in the spinning of cotton by inventions which greatly increased the amount of yarn which a man could spin in a day. Lewis Paul, John Wyatt, James Hargreaves, Samuel Compton and Richard Arkwright all

played their part over half a century. Arkwright eventually succeeded in spinning yarn with power derived first from horses and later from water mills. Arkwright, originally a barber in Bolton, has been bitterly attacked for only putting together the ideas of others, and indeed his patents were annulled by the Courts. It was Arkwright's ingenuity, initiative and capacity for working with his partners which made the success of the power-operated spinning jenny, thereby introducing the factory system into the cotton industry. It was the use of power driven machinery which made the factory system necessary. The industrial revolution had started. James Watt invented and made the new steam engine so that factories no longer needed to be situated where there was water power. Then for seventy or eighty years new industries followed each other in rapid succession. The power loom of Dudley and Cartwright came only slowly into use, but developments in the textile industry led to the building up of a heavy chemical industry on the Mersey. Then George Stephenson, who had made a locomotive, persuaded Joseph Pease to use locomotives instead of horses for traction on the Darlington and Stockton railway which was then under construction. The locomotive was a success, and for nearly a hundred years Britain supplied the world with railways.

Why did these developments take place in one part of England ? What were the favourable conditions ? In Yorkshire and Lancashire and the Midlands there were coal and iron and water power at hand. Transport was becoming easy. The country was being covered by a system of roads and canals, better than the Roman roads which had fallen into decay many centuries before. The men were there too—inventors, craftsmen, managers and merchants. But very similar conditions existed in other parts of the world. Inventions were being made in France and in Germany, but they were suppressed, just as Dudley's use of coal for the production of iron had been suppressed in this country years before ; and often the inventors themselves were eliminated.

It seems that in North Central England there occurred for the first time a system of government and an outlook among the people, combined with certain material and physical conditions, which made it possible, though not easy, for invention and new industries to flourish. None of these developments took place in the London district. Why was this ? Perhaps the City Guilds were too strong and conservative in their outlook for great changes to take place there. Nevertheless once the industrial revolution had started in the north, the British people seized the opportunity. The new industries spread over the

whole country and supplied the world with goods manufactured in British factories.

Other countries could not follow our lead unless they had coal mines, and it was fifty to sixty years before they really got any start at all. I can easily understand why it took them so long. I have visited two non-industrialised countries with a view to building factories there. I found that they had a few good technically trained men and far-sighted business men, but no trained managers, no foremen and few mechanics.

The great industries of this country were built up by our pioneers who were managers, foremen, mechanics and craftsmen of all sorts. Then the scientist and the research worker came on the scene. Perkin, a scientific research chemist, started the synthetic dye industry based upon discoveries made by scientific research. But Perkin, having made as much money as he required, retired before he was forty to the scientific work which he loved, without realising that he had sown the seed of a new technique of industrial development. The same scientific industrial principles were used by the professors of Heidelburg University, who started a dye industry based upon laboratories where science was used in solving the works problems, and where new ideas for industrial development were born. Similar scientific organisations arose in the electrical and optical glass industries in Germany, in the engineering industry in Switzerland and in the electrical industry in America. But in the main British industry continued to be run on the old lines. We could afford to do this because our industries were well established and still profitable. By 1914 there were good small laboratories in some of our industries, but nowhere were large laboratories researching for new industries and few of our managers were scientifically trained.

The foreign manufacturers who were using scientists in all branches of their organisations became serious competitors in our markets. We did not realise the importance of this at first because in some cases their activities were in offshoots or sidelines of our industries. In the chemical industry they made great advances in dyes and drugs, whilst we had to be content to leave this field to them for many years, and we were glad to supply them with some of the raw materials of their industry.

The need for science and research in industry was first realised by us, as a nation, during the first German war, when the Government formed the Department of Scientific and Industrial Research to accelerate the introduction of research into industry. The Research Associations were started and many of them have done good work.

Some of our manufacturers have established large research laboratories and have adopted the scientific industrial method. I do not know of a single case of a firm starting a large research laboratory and not making a success of it.

The problem of introducing this scientific policy into the working of smaller firms is perhaps more difficult, but if under present conditions the smaller firms are to originate new developments they will have to work out some method of introducing science and research into their daily life. I am confident that this can be done. There are the Research Associations, and I hope that some day we shall have the equivalent of a Mellon Institute in this country, for in America it has been a most important factor in the introduction of science and research into many small and large firms.

Let us now consider how new industries arise from a research laboratory.

1. Research may be directed to supplying a well-defined want, or what is believed to be a want. For example, estimates were made of the future supplies of petrol, and it was generally agreed that there would be a world shortage in a few years. Research was commenced on all likely means of making a liquid fuel which might be used in an internal combustion engine. Petrol was being manufactured from coal within ten years.

2. Research may produce a new device, a new chemical or a new plastic which we think may find a use somewhere. Then there must be more research to find and establish a market. The uses of a new material are not obvious at first. Perspex, the transparent plastic clearer than glass, used for the windows of aeroplanes, was a few years ago only an interesting curiosity. To many people in the industry it seemed unlikely that it would ever be of industrial importance. Now it is not only used for the windows of aeroplanes. It is a beautiful plastic for making mouldings of all sorts. Spectacle lenses are made from it, and it is now the principal material for the manufacture of dental plates and artificial teeth, every dentist being familiar with the art of manipulating it.

3. Sometimes research succeeds in lowering the cost of production of some product to such an extent that its use is considerably extended. This may amount to the making of a new industry. Ford's method of making motor cars is an example of this. Another was the synthesis of ammonia which led to the manufacture of sulphate of ammonia on an enormous scale and introduced the use of nitrogenous fertilizers to farmers all over the world.

4. Research also produces new ideas which create a new kind of want—an electric razor, a wireless set, a new kind of drug such as sulphonamide or penicillin, or a specific weed killer which will destroy the weeds without harming the crop.

Let us now consider what happens when we have obtained the knowledge and ideas upon which a new industry may be based. First of all everyone will not recognise the possibilities, and those who do will point out the difficulties and the risks in starting to manufacture something new. If the new industry is to arise at all at least one enthusiast must believe in the commercial and industrial opportunities which are offered. He has to obtain the confidence of his colleagues and persuade them to spend money upon the venture. He does not have to convince them right away that a new industry will certainly arise, but he must get them interested and willing to give him financial and moral support.

Until the introduction of the scientific era a few years ago, new industries were not generally developed in established firms. To develop a new idea a separate company was formed, and generally the man who believed in the possibilities of the new industry staked all his own capital and as much of the capital of his friends as he could obtain on the great adventure. In the modern firm one or two men have to stake their reputations whilst everyone else sits upon the fence to come down eventually on the right side.

Many of us have at one time thought that an economic investigation of the market and of costs of production would make it easy to decide whether a new industry was possible. But this is not the case. Such an investigation is useful and must be made, but it never leads to a definite conclusion. Either there is a market, in which case a guess has to be made whether the new product will make its way by being an improvement or by being cheaper, or there is no market, and then it has to be decided whether a new market can be made.

Whether a project is good or bad is a matter for human judgment. There is no scale by which it can be measured. But however good a project may be, it will never develop into a new industry without some individual providing the drive and determination to make good in face of difficulties, opposition and apathy. A new industry is always started by one or two individuals ; it does not grow naturally out of an organisation. Science, research and organisation are all necessary aids to the man who is providing the drive, but without the direct personal drive there will be no new industry.

This country has often provided the ideas upon which other countries have built up industries. We have indeed done more than

our share of providing ideas, and we have done less than our share of making them into new industries. I think it is because we are only just adopting scientific industrial methods, but from now on I hope that we are going to develop our ideas into industries ourselves. It is being done in some of our industries now, and it has been done wherever it was needed in our war effort. We have the research men, the technical men, and the business men. All we want is the pioneering spirit in every firm. There will be difficulties to be overcome and disappointments to be met, but for those who can stay the course, there will be success in the end.

SESSION III

Scientific Research and Industrial Expansion

PAPER II

MODERNISATION OF PROCESSES AND PLANT

By C. H. DAVY, M.I.MECH.E.,

Chief Research Engineer, Babcock and Wilcox Ltd.

The present very heavy demand on Industry, arising from the necessity to make good the deficiencies and destruction of the war years, has necessitated a condition when all efforts must be concentrated on the production of goods, even if these goods are only in the state of development which was acceptable in 1939. Processes and plant, modern in 1939, have still largely to be used to-day. This unnatural situation arising out of the present demand tends to put into abeyance the normal processes of modernisation and development; but in reality, during the next four years, intensive application of research towards the production of new designs and new methods of manufacture is essential. When the present abnormal demand has been dissipated, competition, particularly in export markets, will be exceptionally keen and business will go to those who have up-to-date designs to sell at economic prices. Goods of outstanding quality, sold at reasonable and competitive prices, can only be produced if the methods of manufacture and the plant used in manufacture are arranged to take advantage of scientific knowledge. Thus, British industry should quickly grasp the advantages obtainable from the application of scientific research to design and manufacturing methods.

As an instrument for the modernisation of processes, research is applied already in many branches of Industry. It presents an exceedingly broad subject for discussion and, by reason of the very wide range of the industries involved, it is difficult to illustrate the subject by attempting to quote actual technical cases. Several papers might be written on each section of Industry, setting out the detailed technical history of the manner in which modernisation of particular processes has been carried out, but without contributing much effective matter to the vital problem of harnessing research efficiently to ensure gradual and continual development in fields where it has not been utilised up to the present.

The word " modernisation " is perhaps in one sense unfortunate, since its root meaning is " to bring into alignment with modern practice," whereas the endeavour should be to move at least a step ahead of present day methods. The procedure of merely copying what has already been done elsewhere involves little need for research. For instance, a machine shop arranged for lineshaft drive might be modernised by adopting individual drive, but little research would be required to accomplish such a change, although statistics might be needed to indicate whether the change would be worth while. It is in the direction of development of processes and plant beyond the limitations of modern practice that research can offer the greatest benefits, and this paper discusses the type of research department best able to attain these ends as part of an industrial organisation.

In recent years research propaganda has tended to stimulate the growth of a conception common among manufacturers that research is associated with and confined within elaborately equipped Research Stations or Laboratories. This idea is quite erroneous and, what is more important, it leads to an entirely false view of the advantages which are to be obtained by applying research to individual process development. A much more ready and eager acceptance of the value and advantage of research would be obtained if the real meaning of the word " Research " was carried in mind. It has been defined as follows : " Diligent investigation in order to ascertain something."

Elaborate apparatus may be found necessary in some instances to attain the desired end, but much work of great practical benefit to mankind has been achieved with the simplest of equipment. This fact should go some way to refute the idea commonly held that research can only be applied to industrial processes by those who have large sums of money to spend on big research staffs and elaborate research equipment. Research is not wholly the prerogative of the department bearing that name, but is frequently carried out by anyone who appreciates he has a problem to solve and has the time and initiative to investigate it logically.

Having made some attempt to remove certain misconceptions, we will consider now the main principles of organisation regulating the successful application of research to process modernisation.

Employment of the Results of Fundamental Research

It has been often stated that the value of fundamental research is measured by the extent to which its results can be brought to practical application for the benefit of mankind. In general, these

results cannot be applied directly to manufacturing processes. Additional work must be done to translate them into terms in which their value and application can be perceived by those responsible for design and production.

The fundamental research worker and the production executive live in entirely different worlds, speak in different languages and measure the value of their work in totally different ways. Men must be available who, by virtue of their training and experience, are equally at home in either territory. In other words, a bridge is wanted over which it is possible to pass to design and production executives, in a readily usable form, the valuable features of any particular piece of fundamental research work recognised as offering possible advantages if applied to design or production methods.

On a number of occasions recently, adverse comparison has been made between the use of research in this country and in the United States. Consideration of the present day position shows that Great Britain is not lacking in fundamental research achievement, but there appear to be a far greater number of bridges available in the United States whereby the fruits of fundamental research are readily and quickly conveyed and translated to a form applicable to actual industrial processes. In this country we need many more bridges and these bridges are, in fact, Industrial Research Departments. If the bridges are to be sufficient in number and efficient in practice, then a much greater pool of qualified Engineers, Physicists, Metallurgists and Chemists is required to be built up so that more firms can initiate Research Departments.

Factors for Success

Industrial Research Departments, if they are to serve Industry adequately in the development and modernisation of works' processes, should be built up and operated to fulfil the following requirements :—

A. Ability to appreciate the channels of research which will provide data needed by the firm to enable it to develop its products and maintain its position in the forefront of progress. This can be achieved through intimate and continual contact with those responsible for design and production.

B (1) Ability on the part of research workers to perceive and extract potentially useful information made available as a result of external research work of applied or fundamental character.

(2) Ability of research workers to perceive and extract the inherent and potential information made available by their own experiments.

C. Ability of research workers to analyse and assess the relative importance of the various parts of the knowledge obtained.

D. Ability of research workers to commit these results to paper so that a balanced picture is produced which includes all the relevant information and reasoning expressed in the simplest terms possible.

E. Ability of the research organisation to present their results in such a form that the interest and eagerness of design and production personnel is immediately stimulated to consider the practical applications of the work.

Some further detailed consideration is desirable of the more important of the principles enumerated and an endeavour is made to deal with these under the following headings :—

Appreciation of Problems Involved

There is an obvious necessity of ensuring that the efforts of the Research Department are directed into the right channels. This is an important feature, particularly at the time when an Industrial Research Department is new in a firm, because, in Industry, a Research Department is regarded as a non-productive section of the business since it is not intended to produce manufactured parts or manufactured materials ; in fact, its only product at any time is information. Consequently there is a tendency for Research Departments in Industry to be classed as non-essentials. The Department has, therefore, first of all to win the confidence of the design and production sides of the business and this end is most rapidly achieved if it can produce useful results in fields which are obviously within the scope of the business of the Company of which it forms part.

It will be appreciated that much of the success of the Research Department will depend upon its having an intimate knowledge of the difficulties which beset the designers and those engaged in production. Actual experience shows that one of the best means for obtaining this result at executive level is the inception of a Research and Development Committee, meeting at frequent intervals, the personnel of the Committee being composed of those actively engaged in design, manufacture and research. With the

same end in view, research workers should be encouraged to maintain contact with those serving in design and production departments and should have freedom of access to workshops and sites where full scale erected plant is put into operation.

In some quarters it is considered undesirable that the routine testing of materials and parts required in connection with production should be carried out by the Research Department. Practical experience of industrial research shows that there are distinct and considerable advantages to be gained by a combination of Works' Testing Laboratory and Research Department. Firstly, it is an economical arrangement, since dual purpose apparatus can be provided and such apparatus can better be maintained by research-minded personnel. Secondly, better class personnel can be available for supervising routine testing, whereas in a Works' Laboratory operating by itself, the load to be carried might well be insufficient to warrant the expenditure which would arise from the availability of highly qualified staff. The most important feature of the combined arrangement is that it provides a channel through which collaboration between Works' personnel and Research Department staff is continuously maintained and serves as a means whereby the research worker can be acquainted with actual production problems. Thus, when presented with production problems, the research worker has already an understanding of the production background. Frequent contact on a common ground through this means is helpful in encouraging mutual confidence between those engaged on production and research, and thus stimulates the rapid application of the results of research to production.

Research Personnel

The ability of the research worker to extract relevant matter from external or internal work, analyse it, and report in a balanced manner, is an essential factor for success. In a Research Department engaged in the Engineering Industry the staff will be made up of experienced Engineers, some of whom may be highly qualified from the academic viewpoint, whilst others, equally useful, may have excellent practical experience but academic qualifications of a lesser order. Qualified Physicists will be required to handle the fundamental aspects of the problems ; Metallurgists will be needed, also Chemists. In addition there will be a number of unqualified assistants who in their particular sphere of work are as necessary as the highly qualified men. The balance of these various classes

of research workers is all important if the best result is to be obtained.

A tendency to overburden the research staff with men of the highest academic qualifications may lead to research reports in which the academic side of the question is unduly over-stressed in language not readily understood by practical men, with the result that the report is not read or understood by the design and production sides for whom it is intended, and the object of the Research Department is thus defeated.

If the number of highly qualified research workers is too low, then there is a liability that results, if obtained at all, will be made available after an unduly great lapse of time due to the use of cumbersome and possibly incorrect methods of approach. Delay in presenting results may mean that the problem must be settled by arbitrary methods because the job cannot wait.

The actual balance capable of giving the best results will vary from Industry to Industry. In an Engineering Research Department, Engineers, Physicists, Metallurgists and Chemists holding University degrees are required, but in varying numbers, dependent upon the nature of the products of the industry and even upon the problems dealt with from time to time; for example, a long-term research of a fundamental character might require a team of men of special experience and in numbers not normally required in the permanent establishment.

The scope covered by one particular Engineering Research Department can be quoted briefly as an example of the work to be covered in individual industries :—

Combustion Processes:

Processes of combustion of fuels in the furnaces of steam generating plant and in industrial heating furnaces employed in the heating of metals both prior to forging operations and in heat treatments such as normalising, annealing and low temperature stress relief.

This work is of particular importance from the point of view of increasing the range of coals which can be burned and decreasing the weight of coal required for any particular process, thus conserving the fuel resources of the country. The work involves fundamental study of the physical properties of fuels and of the gases produced in the process of combustion.

Heat Transfer:

Transmission of heat from hot gases to water, steam and air. This work has its most direct application to the design of the large steam generating plants used in the generation of electricity and also in those steam generating plants where steam is required in large quantities for process purposes. By the application of research and development over a period of some years, the recuperation of heat released in the burning of coal has been improved from an efficiency of about 72% to a present day efficiency of the order of 90% of the calorific value of the coal. The main problem involves close consideration of such factors as heat radiation and insulation.

Metals under the effect of High Temperature:

Behaviour of metals under the effect of high temperature, with particular reference to alloy steels in tubular form used in the heat exchangers of the superheating sections of high pressure steam generating plant.

The superheating of steam to temperatures ranging between 900° and 1000°F. increases the thermal efficiency of the steam cycle so that the maximum amount of energy can be obtained from each lb. of steam generated, whilst high steam temperatures also permit the use of high steam pressure. By the use of the combined effect of high steam temperature and pressure, when applied to the generation of electricity, the steam cycle efficiency is now 35% greater than it was 20 years ago.

Corrosion, wear and abrasion of Metals:

Stress Analysis:

Investigation of the design of stressed component parts, with particular application to vessels containing steam and water under the effect of high pressure.

Mechanical Operations:

Investigation of mechanical operations such as welding, forging, the development of pressure tight joints which can be assembled and dismantled for maintenance purposes, the securing of tubes into heat exchangers to withstand high pressure by such operations as expanding, etc.

All the research subjects detailed above are interconnected and certain of them involve comprehensive long-term research occupying the continuous service of highly qualified staff.

Dissemination and Utilisation of Results:

Far too little consideration is given to this aspect of research work and it is desirable to repeat that an Industrial Research Department has only one product to offer, namely, Information. If that information is readily absorbed by those to whom it is made available, then the Research Department is indeed successful.

Research may be directed into the correct channels and the research work itself may be carried out with a reasonably high degree of efficiency, but unless the results are presented to the right people and in a form such that they are easily and wholly understood by the design and production personnel, the whole efforts of the Research Department will be nullified. It is not always appreciated that it is perhaps the most important function of the research worker in industry to " sell his own work " and consequently it is difficult to stress sufficiently the necessity for a high standard of presentation of research results. This feature is regarded as of such high importance that it is considered worth while to describe the main requirements of research reports, even if some of these requirements appear to be elementary in character :—

(i) Easily readable:

Typescript should be clear so that it can be read without fatigue.

A standard form of report should be adopted throughout so that those who receive them may in time know instinctively where any particular class of information will be found.

They should be written in the language commonly used by the readers. Where highly technical commentary must of necessity be included, it should be presented in Appendices.

(ii) Stimulating interest:

This is important, since executive personnel in Design and Production Departments are of necessity much burdened with work. If research reports can appear, in the course of a most hasty perusal, to be exciting to the appetite of the reader, time will be found for a thorough examination and consideration of the report. Money spent on good clear illustrations, together with simple bold diagrams, will be more than repaid by the interest created.

A worth while practice is the inclusion at the commencement of the report of the shortest possible statement of the problem and the result of the work in the broadest and simplest terms.

(iii) **Clarity of meaning:**

It is essential that research reports be written in language which is not ambiguous ; expressions capable of two different interpretations should be avoided at all costs.

(iv) **Individual appearance:**

It is well to see that reports presented by a Research Department are made up in covers or folders having characteristics quite different from those used by any other department in the organisation. This leaves no doubt in the mind of the recipient as to the source from which the report has come, and with the course of time it should be possible to build up an automatic acceptance in the mind of the recipient that the information contained in reports of that class can be relied upon as a true and unbiased statement of the case on the facts which it has been possible to reveal.

It is believed that acceptance of the value of research work in the modernisation of industrial processes might spread much more widely and with greater rapidity if more attention on the part of Research Departments was paid to this urgent question of report presentation. Large sums of money are readily voted for expenditure on actual research work, but expenditure on presentation of results is apparently often totally inadequate. It should be the business of every Industrial Research Department to search out and investigate every means by which information can be transferred from the mind of one human being to another. Much could be done by the use of the cinematograph as an introductory method to arouse interest, bearing in mind that once the interest of the design or production executive has been stimulated, he will in the majority of cases readily arrange for his assistants to go thoroughly into the full details of the results reported with a view to utilising them for the betterment of his designs or his production methods.

So far as the modernisation of processes and plant is concerned, the Research Department which forms part of the organisation of a firm engaged in Industry has possibly some advantage over the Research Association or the Government Research Station because of its intimate connection with the source of the problem and its association with those who can make best use of the results. In these respects the Research Association is somewhat better placed than the Government Research Station. It has been suggested that Research Associations can take the place of Research Departments forming parts of firms engaged in Industry, but there can be little doubt that the efficiency of contact will be considerably increased if a Research

Association is able to make and maintain its contacts with Industry through the Research Departments of individual firms, since the latter are best able to state the problem in the first case and see that the results of the Research Associations' work reach the right quarters when the work is completed.

Conclusion :

At the risk of repetition, attention must be focused upon the human factor which is so essential for the success of a Research Department. To illustrate this, it will be realised that the efficiency of the department as a whole is the product of the individual efficiencies of fulfilment of each of the requirements enumerated earlier in this paper. Some Research Departments concentrate, with varying degrees of success, on the fulfilment of the requirements connected with the internal set-up of the department itself, but fail to realise that they should have great influence beyond the department in the efficiency with which the results of their work are assimilated by others. For obvious reasons, external assimilation of research results is likely to take place at a lower efficiency level. If, for example, the assimilation efficiency is zero, then the combined efficiency of the whole of the work from start to finish is also zero, no matter how high the efficiency may have been in the other sections. There is sometimes insufficient realisation that the Research Department has considerable responsibility in the direction of assimilation. It is not only their duty to produce results—they have also to " sell " them.

SESSION III

Scientific Research and Industrial Expansion

PAPER III

THE PART CO-OPERATIVE RESEARCH CAN PLAY

By A. J. PHILPOT, C.B.E., M.A., B.Sc.,

Director of the British Scientific Instrument Research Association.

There is general agreement that the unprecedented expansion of industry, both in total output and in variety of product, which we have witnessed during the past seven years has been closely related to the equally unprecedented research effort which has accompanied it. The moral of this has not been missed and there exists to-day a very general determination that in our attempt to maintain our industrial facilities by an expansion of the variety and output of our peace-time manufactures there shall not be lacking an adequate background of research. It might, therefore, be thought that the ground to be covered in this paper has already been very thoroughly ploughed and, indeed, if the complete agreement which exists on the necessity for research were matched by its application and an equally general agreement on the plan of research for industry there would be little point in reading this paper. Signs, however, are not lacking that the new-born belief in the vitalizing impact of research on industry does not necessarily include a faith in the virtues and possibilities of co-operative research, and that the immediate preferential advantages of individualistic research make a greater appeal, in some quarters, than do the more deep-seated and permanent advantages claimed for the co-operative system.

It is, however, relevant to remark that the impact of research on the industrial war effort, which has resulted in the universal recognition of the magnitude of the part which research must play in industrial life in future, relates to co-ordinated co-operative research and that there has taken place in the immediate past, in spite of instances of unnecessary duplication and indiscriminating secrecy, a large-scale and successful experiment in research of this nature. The war effort itself provides a most striking example of the immediate and powerful effect which boldly conceived co-operative research can have on industrial expansion.

The Example of Radar

Notwithstanding the evidence furnished by the war it is well to remind ourselves that in the most academic research there may be found the origins of industrial expansion and even of the emergence of new industries. No better example can be given than that of Radar cited by Sir Frank Smith at a recent conference on "Recording and Control in the Chemical Industry." Radar was one of the great war weapons and it is certain that it will play no small part in shaping our new way of life. The possibility of the application of the principles underlying radar to military and civil uses depended entirely on the existence of a means of measuring exceedingly minute intervals of time. Such a means was found in the cathode ray oscilloscope. The direct ancestor of this instrument is, however, the primitive cathode ray tube used by Sir J. J. Thomson in his classical researches in which the deviation in a cathode ray stream, when passing through electric and magnetic fields, was observed and measured. It can, therefore, be truly said that the work of Sir J. J. Thomson in the closing years of the last century provided the seed from which the great industry associated with radar and radio has grown, and that the advance in science associated with his name has resulted in the creation of a new and ever-growing industry.

It should be observed, however, that the cathode ray tube remained for many years the tool of the academic research worker only, and was used by him to widen the boundaries of the knowledge of the nature and behaviour of the electron. These boundaries were extended in the most general manner and in every direction and it is upon the broad general knowledge thus obtained that all particular industrial applications have been built. It should further be observed that the academic attack on such a problem is, by the very conditions under which academic research is prosecuted, co-operative in its nature. During the past fifty years of amazing scientific progress the research worker has claimed, as the just reward of his labours, the right to publish his results and to do so immediately. The scientist engaged in research has thus been able to include in the structure of his own work knowledge obtained by his immediate contemporaries. The learned societies have been the co-ordinating authority. It is from this great body of co-ordinated research that such rich harvests have been reaped in the era of industrial application.

The Time Lag in Development

Much has been said concerning the time lag which occurs between the unearthing of new knowledge by pure scientific research and the

large-scale industrial application of that knowledge. In the case cited above, industrial application took place from thirty to fifty years after the new advance in scientific knowledge ; but the pace of the broadening and enlarging of the original advance was exceedingly rapid. What then is the explanation of the dead period which has apparently inevitably occurred between the achievement of a very full measure of academic knowledge of a new phenomenon and its useful exploitation by industry ? Is not one very real cause to be found in the fact that the final specific application has to be based on knowledge and techniques acquired through basic applied research, prosecuted on very general lines, and that this basic background research has progressed unduly slowly through its being unnecessarily duplicated, and has been handicapped by limited facilities consequent upon its being prosecuted in a parochial spirit ? Once the academic attack on the mysteries of a new phenomenon gets under way, the speed of advance is remarkable and the co-operative conditions under which that attack is made is not without significance in planning the later attack on application.

Co-operative Research within an Industry

There are two phases of co-operative industrial research, the one relatively restricted and the other more comprehensive. There is in the first place co-operative research within a single industry—research into the problems of practical application of science peculiar to that industry. In parenthesis it should be remarked that an industry, like man himself, cannot live unto itself, and it is very doubtful whether there are any problems completely peculiar to any one industry. Every industry does, however, have its own domestic research problems, the boundaries of which, although not sharply defined, do include mainly the interests and purview of the particular industry. That scientific research is essential to industrial progress and expansion is accepted, but how is the *average* industrial unit to carry out the necessary research ? It may, of course, decide that it will concentrate what resources it has on the prosecution of a restricted programme of research limited by one or two of its own dominant and peculiar interests and that it will either carry out such research within its own walls or extra-murally under its own strict control and for its own sole benefit. From a superficial standpoint there might appear to be some sense in such a policy, but it completely ignores the basic fact that the directions in which research should be prosecuted and the type of investigations to be undertaken will only become apparent when there exists that adequate background knowledge which can only be obtained through large and comprehensive research surveys of a very general nature. Such surveys are quite beyond the resources

of the average unit and should, in any case, from elementary considerations of economy of finances and manpower, be carried out centrally under co-ordinated and co-operative arrangements. The position of an industrial firm which has no research facilities is lamentably weak, but that of a firm which conducts research in walled-in laboratories with no access to the broad fields of vital basic knowledge is far from being strong.

A research association provides a smooth channel through which the peculiar genius of the academic worker can be enlisted to aid in the solution of problems of applied research which have proved intractable through absence of vital fundamental knowledge. The research association can, also, through its contact with sister institutions, most suitably arrange that the research facilities of more than one industry, together with those of non-industrial organisations, shall be utilised in the solution of problems of a wide general interest. The present structure of industry makes it imperative that the average industrial unit should be linked with a system of co-operative research which will enable it to conduct its own research activities on a basis of background research which it cannot provide itself.

The case for the participation of the larger industrial units in a system of co-operative research obviously differs from that applicable to the smaller units, but it is only a difference in degree. Attention here is directed to one facet only of that case. It is generally agreed that pure fundamental academic research must be completely detached in its viewpoint, and it is equally necessary that a large degree of detachment should be associated with the prosecution of the background research which provides the basis of industrial application. The very fact that research is being carried out with utilitarian application in view must lessen the degree of detachment, but nevertheless basic applied research should be carried out under as little pressure as possible from particular and circumscribed interests. It is difficult, if not impossible, for any industrial concern to prevent the very sharply defined interests of the workshop and factory filtering into the research laboratory, and intimate contact with a co-operative research institution offers a means of providing an atmosphere of detachment from domestic interests and of correcting any tendency for the direction of research being unduly influenced by those interests.

Co-operative Research on a Wider Basis

So much for co-operative research within any one industry. There remains the more comprehensive co-operation which should naturally result from the interdependence of industries and from

their common interests in many general lines of investigation. It has already been remarked that no industry can live unto itself. Each industry uses the products of other industries, and should be interested in the use of its own products by others ; also conversely no product is utilised by one industry alone. One of the conditions of industrial expansion is the adequate provision of new materials and of modifications of old materials. It is essential that the advance of an industry should not be unnecessarily hindered by the absence of such provision, but that there should be available to each industry products having properties most suited to its needs. If this end is to be achieved, research and development must be unflaggingly prosecuted, but too frequently in the past the onus for the prosecution of this work has been placed by the user on the producer, and by the producer on the user. It has not been uncommon for one industry requiring a certain product to wait until the producing industry has, in the course of possibly slow development, evolved a variety of product, under stress of quite unrelated interests, which in its properties approximately fulfils the first industry's requirements. Alternatively, the user industry may have struggled under conditions of inadequate experience and improvised facilities, to carry out the necessary investigations itself. The number of industries using refractories, the general incursion of scientific instruments into all industries and the wide variety of special materials used in their production, the wide uses of glasses and plastics, the universality of steels and of non-ferrous metals, and many other examples, all indicate the magnitude and variety of common research interests. There can surely be no better way of ensuring that the maximum consideration shall be given to each separate interest of the participants in the common interest than by the widespread inauguration of inter-industrial co-operative researches. This is no new idea and has, in fact, been exploited most successfully in the past.

One very striking example is furnished by the collaboration between the British Iron and Steel Research Association, the British Electrical and Allied Industrial Research Association, and the National Physical Laboratory over a long period of years in connection with the use of steel at high temperatures, the result of which was the production of a steel in which the phenomenon of "creep" was greatly reduced. This permitted the working temperatures of the steam in the electrical generating plants to be raised to a total temperature of upwards of 900° F. so that the thermal efficiency of principal power stations has been increased since 1930 by 33 per cent. Such a result is, however, but the logical outcome of the sharing of problems of common interest and of co-operation in solving them. It is not surprising that the

British Iron and Steel Research Association, in its post-war programme, proposes to collaborate with, contribute to, and exchange representation on the various committees of no less than fifteen research associations and Government laboratories.

The successful outcome of the experiment in collaboration cited above throws into sharp relief the difficulties which have been experienced in this country by any industry in obtaining from another industry special varieties of materials which are of a "key" nature but which may, or may not, be in great demand. In some industrial countries such difficulties are practically non-existent. The result of the general adoption of widespread inter-industrial co-operative research would bring about, through the close association of the technicians of the various industries a much wider knowledge of, and deeper sympathy with, the special requirements of an individual industry, and would automatically increase the rate of industrial progress and growth of competitive power.

Conclusion

Industry in this country must expand, but that expansion has to be achieved under strained conditions of scientific man-power and of financial resources. Surely, the general considerations which have been briefly indicated in this paper and the immediate circumstances conspire to urge the necessity for the utmost collaboration in our industrial research and the pooling of resources both of any one industry and, where necessary, of groups of industries. Mountains of difficulty confront industry in the immediate future, but faith in the dynamic power of co-operative research can be a potent agent in their removal.

SESSION III

Scientific Research and Industrial Expansion

DISCUSSION

"Industrial Expansion and Full Employment"

SIR HENRY TIZARD, F.R.S. (President of Magdalen College, Oxford) said that because the prestige of British scientists was never higher than to-day, it was important that scientists did not overplay their hands. It was especially important in considering the influence of scientific research on industrial expansion in these days when there was a shortage of scientists to decide what it was most important to do.

Eminent economists preaching the doctrine of full employment did not rely in their arguments on the help that science might bring in the future; their view was that whatever the state of applied science, there could be full employment if Governments took the right action. Perhaps, fortunately for some of them, owing to world conditions, their theories were not likely to be tested adequately in their lifetime. There could only be real expansion if more people were employed in productive industries, or if the efficiency of production was steadily increased. There seemed however a tendency in a modern industrial state, as time goes by, for a smaller instead of a greater proportion to be gainfully employed on productive work. Fewer people were working in industry and more were telling them how to do it. Where was the balance to be struck between those who planned and those who worked to achieve maximum production. The solution of this problem had to be approached by trial and error, but there was a strong human incentive to fill the ranks of the planners rather than the 'doers'.

An increase in the efficiency of production could be achieved in a number of ways. Medical research with all that it implied bore a great indirect influence on industrial prosperity. The loss of industrial output every year by ill health was far greater than could be saved if all the coal of the power stations in the country were replaced by 'atomic' furnaces, and if the atomic energy cost nothing.

He thought that at last it could be assumed that everyone realised the value and importance of labour saving, and appreciated that it was not the chief cause of unemployment. Although there could be no industrial expansion without labour saving, we did not pay enough

attention to this factor. Many of the machines which used mechanical power were imported; the incentive to improve machine and plant design appeared on the whole to have passed to foreign countries.

Mr. Davy was right to emphasise the importance of the application of science to design and manufacturing methods, and pointed out that such work was best done at the source and in close association with those who could make the best use of the results. Industrial Research Associations could do far more to help in this direction, had they command of the necessary funds. The raising of the average efficiency of the staple industries was just as important as the introduction of new industries, and required just as much research, although of a different kind. He agreed with Mr. Davy that at a time of uncompetitive industrial prosperity there was the risk that the modernisation of plant and processes would be neglected. This needed to be emphasised, not to be obscured by high flown talk about fundamental research, which broadly speaking should be left to the Universities. Nine out of ten scientists did their best and most useful work when they are objectively minded, and in most industries one scientifically educated engineer was worth two research scientists in the laboratory. There was a serious lack of such engineers here, owing to our comparative neglect of Schools of Technology of front rank.

One difficulty in discussing the value of research in industry was that people attached such different meanings to the word. At the one extreme was found the industrialist who proudly displayed his testing laboratory as his research department; and at the other was the inexperienced scientist to whom fundamental research was a fetish. The first had been described as one who regards the scientist as a kind of plumber to be called in when the pipes freeze; and the second was the kind of man who would have argued years ago that a clear understanding of the action of light on silver salts was a necessary pre-requisite of a flourishing photographic industry. A testing laboratory is a necessary running cost; a research laboratory is a capital investment. But the staff of an industrial research laboratory should always have a definite practical object in their work, however recondite it may appear to be. That was the way that new industries arise; they did not spring ready made from the Universities; they depended on the development of new ideas by men whose intellectual reward was to see the results of their work embodied in practice rather than recorded in a scientific journal. As Dr. Slade said "we have indeed done more than our share of providing ideas, and we have done less than our share of making them into new industries."

To sum up Sir Henry felt that industrial expansion in Great Britain depended essentially on the continuous improvement of

existing plant and processes and on the eager development of new ideas in industrial research organisation; that this called for a far greater expenditure on large scale experiment and research than had been incurred in the past; that the real need in British industry was for men of scientific education who have the outlook of the engineer rather than that of the pure scientist; and that they would not be forthcoming in sufficient numbers unless we greatly expanded and improved our Schools of Technology.

"Silk"

Mr. Wallace Ellison (of Brocklehurst-Whiston Amalgamated Ltd.) said that the branch of the textile industry in which he was engaged, pure silk, owed a great debt to the scientific research work of Pasteur on the diseases of silk worms. Research had profoundly modified textile practice in other fields than his own and had enlarged beyond measure the volume of raw materials which were available to mankind. The work done at the Shirley Institute on cotton and rayon was frequently as valuable to the silk industry as research work on silk itself.

There was scope for the most fruitful co-operation between research workers in most branches of engineering and research workers and industrialists throughout the whole range of the textile industries. Great things undoubtedly lay ahead of us in scientific discovery and invention but these things in themselves were not enough. He quoted the words of Sir Alfred Ewing:

> "We are acutely aware that the engineer's gifts have been and may be grievously abused. In some there is potential tragedy as well as present burden. Man was ethically unprepared for so great a bounty. In the slow evolution of morals he is still unfit for the tremendous responsibilities it entails. The command of nature has been put into his hands before he knows how to command himself."

The end was, after all, immeasurably more important than the means. Ordinary folk—especially the young who were coming back from the war—looked to our intellectual élite to bear these things also in mind and as far as lay in their power to guide us aright.

"Consumer Research and the Time Lag"

Mr. J. Ryan (of the Metal Box Co. Ltd.) spoke of the time lag which inevitably occurs between the attaining of academic knowledge

and its useful exploitation by industry. During the war this had been reduced because consumer needs in the form of war requirements were really urgent and well defined. It was essential therefore that in peace this contact between research, design, and production should be extended to cover the commercial side, and the commercial man himself must be keen to supply human wants and needs.

Research was also needed into consumer needs, and it should not be forgotten it required knowledge and appreciation on the part of commerce to state clearly what was wanted. A great degree of skill was required in suggesting how various discoveries could open the door to new resources and offer new opportunities and create potential markets.

He trusted that the British Institute of Management, which it was hoped would come into existence soon, would be able to cover this at present somewhat neglected aspect and thus help reduce the time lag between scientific achievements and industrial production.

"Industrial Expansion and Purchasing Power"

MR. ANTHONY VICKERS (of the Hydraulic Coupling & Engineering Co. Ltd.) said that industrial expansion could not be maintained indefinitely unless there was increased purchasing power. In pre-war days fear of unemployment was a great bar to technical progress because the full output of factories and mines was not always bought and in consequence output was restricted.

In 1938 owing to modernisation and improved efficiency in the production of iron and steel only 18,000,000 tons of coal were required (to produce more iron and steel) instead of 30,000,000 tons in 1920. This had resulted in 40,000 miners being out of work due to lack of purchasing power. It was therefore important for stability and freedom of enterprise to have research into the means of consumption as well as into the means of production, because it was useless to produce unless people were able to buy.

"Development Associations"

DR. E. G. WEST (of the Aluminium Development Association) referred to the work of the Development Associations which had sprung up in recent years, sponsored entirely by private enterprise, charged with the important function of stimulating interest in new employment of metals in the user industries. The Development Associations did not overlap the Research Associations or the sales

and technical departments of individual companies. They acted however as a channel through which problems were brought to the attention of appropriate Research Organisations and they also interpreted research results into appropriate language for the engineers and industrialists of the consuming industries.

Pilot production runs could be undertaken and prototypes could be designed in collaboration with the appropriate organisations. The Development Association was also in an excellent position to place the technical case of an industry before outside bodies including Government departments and local authorities. He asked that the Development Association in the future should be recognised and fitted into the general organisation of research.

"Publication in Relation to the Export Drive"

Dr. C. R. Curtis (of Solus Electrical Ltd.) asked at what point the results of scientific investigation should be made public, bearing in mind that by doing so they would be handed out to overseas competitors of British industry.

He thought it was agreed that the results of pure research undertaken by scientists for the benefit of the world should be widely published. The work of the industrial research department began where they stopped. He thought that secrecy should be preserved until the results had been applied, so that British industry was able to compete abroad and provide the exports which were so necessary.

Until industry was so organised that all goods produced could be sold either at home or abroad, it was inevitable that much research was going to be wasted. He considered that there were inventions in existence and scientific knowledge available which, if applied, would disrupt the social fabric in a very short space of time. At this stage it was vital to consider the economic aspects of the application of science. If a new invention which could utilise the work of four men instead of eight was applied, it should be operated so that all eight men worked for a shorter period of time.

"Integrating the Research Department"

Dr. S. A. Main (of Hadfields Ltd., Sheffield) considered that the contacts between the research and production departments were in many cases inadequate. It was necessary for the research department

to be integrated into the whole business organisation. The manner in which this was to be done depended very largely on the nature of the products of the firm and the way the firm's organisation had been built up in the past.

It would be helpful if scientists, and particularly scientists in industry, could cultivate clarity in reports and avoid making a fetish of scientific jargon. He also felt that while Research Associations filled a present day vital need, their progress was not helped by overstating the claims of what they had achieved.

"Responsibility of the Management"

MR. NORMAN CLARK (Management Consultant) said that in every firm it was necessary to have one Director whose special job it was to keep in touch with general and specific development in his own and in allied industries, so that constant and regular attention was given to research at the top. The Director in question should be a man to whom the research staff could look for encouragement and leadership and who would represent them and give them status at Board level.

The results British industry achieved would depend not only on its research workers, but on the degree of welcome and encouragement accorded to their efforts by the higher managements of British concerns, large and small.

"Scientific and Industrial Expansion" (*Communicated*)

MR. R. C. SMART (Mining Engineer and Surveyor). To a Consulting Engineer and Economist it is clear that the future of this country depends on the character of recognition accorded to the efficiency of its productive forces. Industrial progress is governed by Organisation, Scientific Method (research) and the Machine. The full development of applied research in this country is immediately faced with a dearth of qualified personnel. For example, one person per 1,000 attends a University in this country compared with 25 in America, and only 800 engineers graduate per annum as compared with 12,000 in America. Over £500 millions are required for the technical re-equipment of the basic industries.

Industrial expansion can only be sought along modern lines of approach and to this end industrial research (technical and economic) must be a prime function not only of Universities but of selected Technical Colleges. Training in Management and Industrial

Administration has been conspicuously neglected in this country. Traditional orthodoxy of outlook has conspired to the neglect of Applied Research whilst secretiveness and narrow obstinacy have prevented frank, objective analysis of industry's problems.

This ' state of mind ' of those ' in high places ' lacking the requisite technical knowledge lies deeply at the root of this country's relative (and in many cases absolute) decline in industrial potential during the present century which has witnessed the undisputed dominance of German and American Technology and Engineering. These factors critically govern any question of industrial expansion.

Two industrial surveys by the writer may be quoted (a) " The Economics of the Coal Industry "—published in 1930 and now accepted in the Reid Report—(b) " Britain's Peril "—published in 1932—a suggestion in this book for a Central Authority to maintain constant review of factors affecting efficiency of production has at long last now been partially recognised by the Board of Trade.

SESSION IV.

THE APPLICATION OF RESEARCH IN INDUSTRY

Address by the Chairman

The Right Hon. Sir John Anderson, F.R.S., M.P.

I am greatly honoured by having been invited to take the Chair at the concluding session of what I am sure has been a very fruitful conference on research and industry—a subject of surpassing interest and importance to us all.

It would be natural that a conference of this kind should comprise four elements—those who believe in research, those who are sceptical, the hostile and the indifferent, that is, those who do not know what it is all about and hardly care. Before the first Great War, I have no doubt that the first of these groups would have been the smallest, and the last by far the largest.

To-day, I hope and believe the positions are reversed and that those who are either sceptical, hostile or indifferent form a very small minority. But it by no means follows that everything is yet as it should be.

If you will bear with me I should like to tell you where I think some rather fundamental improvements and readjustments are still required. I trust you will not think it out of place if, for this purpose, I go beyond the scope of your prearranged discussions and deal for a few moments with the background of what you have been considering, that is to say, with the supply, training and distribution of men of science.

I do this because both industrialists and scientists have a part to play in getting things right as I shall hope to show.

It may, I think, fairly be claimed that the efforts that have been made to bring science to bear with full weight upon industry have been successful in two main directions.

On the whole, the attitude of industry towards science now leaves little to be desired; and, in the all-important matter of finance, greatly increased university grants, together with an entirely novel

system of tax relief, enabling expenditure by industry on research, including capital expenditure and grants to outside bodies for research, to be met out of untaxed income, will make an immense difference as soon as full advantage is taken of it. There is, no doubt, still much to be learnt about the technique of conducting and applying research in industry, as the discussions in this Conference have shown. I will have a few words to say on this aspect before I sit down, but I want now to state quite bluntly—and this is the main point that I have to make—that, in my judgment, there are grave defects in our higher educational system which it is essential to correct.

In the first place, the higher teaching of science is directed too exclusively to the creation of specialists. It is not so in the sister Faculty of Arts. The teaching of classics has never been carried on with the main purpose of equipping men to teach or to conduct researches in philology or classical archæology. A balance has there been maintained, as it should be, between the cultural and the utilitarian aspects of university training. On the other hand, little or no thought seems to have been given to the cultural possibilities of scientific subjects.

This is surely all wrong and, from a practical standpoint, two evils, I suggest, result. We have created a community in which, outside the ranks of specialists, far too few people have any scientific training at all. I do not hesitate to say that the administrative branches of the Civil Service would be better equipped for their tasks if they contained a reasonable proportion of men and women with scientific training, and I expect the same is true of administrators in commerce and industry. That is one aspect. The converse also holds that the scientist, being marked down from the outset for a specialist career, is too often launched on the world with an inadequate general grounding. If these defects, springing from a single root cause, can be corrected, we shall have a better balanced community, and, I believe, have less controversy about the proper relation of the specialist to the administrator, greater efficiency and a better understanding all round.

Incidentally, applied science should no longer be regarded as academically inferior to pure science. I recall that when I was a student at Leipzig, three large university institutes, each maintaining a number of professors, and all of equal status, were devoted to chemistry. One of these was the Institute of Applied Chemistry. The memory of such great figures as Lord Kelvin, or that remarkable man, Dr. Lanchester, who died the other day, should serve to clinch the matter.

I have dealt with my first point. My second point is that there has been a lack of co-ordination between the Universities, leading to

what Mr. Churchill once called "overlaps and underlaps", and too little contact between Universities and industry. This criticism, too, has an important practical aspect. We lag seriously behind other countries, not America only but countries like Belgium, Holland and Switzerland, in the number of scientists and technicians available to industry. There is a shortage which it will take five to ten years at least to make up. It is vital during this period that we should use our limited resources to the best advantage. A system of priorities must be established. Estimates of relative urgency must be made and, by a combined effort on the part of the Universities, each doing the job it is best equipped to perform, with the co-operation of parents and teachers, a maximum contribution to the country's needs must be made. How this can best be achieved is now under the consideration of a Government Committee. I would merely, in passing, commend the example of Manchester, where a regional Research Council has been established by the University and the Chamber of Commerce jointly. Such a body seems to me well suited to frame estimates of requirements for a large area of the country and frame proposals for meeting them.

These are, of course, matters in which the central Government must take a hand, and, in that connection, I should like to say that, in my view, among the fundamental reforms required, and one of the most urgent, is some strengthening in the machinery of Government for handling scientific questions. I do not advocate a Minister or a Ministry of Science. I believe that to be a mistaken conception. Most Departments of State have to have recourse to science in some part of their work, and should be free to develop their own organisation. But there are scientific problems beyond the scope of departmental responsibilities in which the Government should take a hand, and, for that purpose, some one Minister should be designated and equipped with the necessary staff, which need not be large but should be of the highest quality. The obvious Minister for this purpose is the Lord President of the Council, who is already responsible for the three main extra-departmental scientific organisations: the D.S.I.R., the Medical Research Council and the Agricultural Research Council. The new organisation, covering as it must the whole field of science, should lie outside these but should use all or any of them as circumstances may require.

Now I have so far dealt, as I promised, with matters of a general character falling outside the scope of your organised discussions and, before I sit down, I should like to offer just a few comments on the two papers to be discussed to-day. In doing so, I shall try to avoid clashing with Sir William Larke who is to review the Conference as a whole at the end of this Session.

In contrast with the earlier sessions, in which the emphasis was on what can be achieved by research, we are concerned this afternoon with the processes by which research can be brought to bear on the problems of industry. The two papers between them cover the whole field, dealing as they do respectively with firms large enough to maintain a separate research organisation, and those too small to do so, and I am sure we are all greatly indebted to the authors for their very practical and most valuable suggestions.

One of the important problems is that of reducing the time lag between a scientific discovery and its application to practical ends. Nearly every scientific discovery seems sooner or later to find a practical application, and the closer the association of scientists and industrialists, the shorter the interval will tend to be. In this connection I have been reminded of a remarkable passage in Bacon's "New Atlantis". Among the staff described as occupying Salomon's House of Science are "three that bend themselves looking into the experiments of their fellows and cast about how to draw out of them things of use and practice for men's life and knowledge. These we call 'dowry-men or benefactors'." Probably Sir Raymond Streat would call them "cross-fertilisers" but, whatever the title, it seems to me that there is much to be said in favour of the appointment of such men by firms of all types.

I should like once more to emphasise the importance of cutting down the time-lag. It is stated in the Federation's report on Industrial Research: "To be first in the field of application is of even greater advantage to a country than to have been the birthplace of the discovery." Most of the scientific and technical discoveries on which our modern civilisation rests had their origin here and far too many of them were developed elsewhere. To put this right is one of the urgent tasks, and I wonder if there is not something that might be done beyond Sir Raymond Streat's suggestion, with which I am in entire agreement, that every firm should employ at least one man to keep track of new developments in the firm's industry. I have in mind something like the Mellon Institute or the Battelle Institute which could undertake research or development work for individual firms on a payment basis, thereby supplementing the work of research associations which cater for the more general requirements of an entire industry or group of industries.

Finally, may I refer to Dr. Dunsheath's most interesting suggestions about the environmental conditions of work of research staffs. The organised employment of scientists in industry is a comparatively new development and it may well be that the optimum conditions have not yet been fully worked out. Here is a further subject of study which I commend to the Federation for another day.

SESSION IV

The Application of Research in Industry

PAPER I

THE FIRM WITH A RESEARCH DEPARTMENT

By P. DUNSHEATH, C.B.E., M.A., D.Sc.

President of the Institution of Electrical Engineers (1945-6) and Director and Chief Engineer, W. T. Henley's Telegraph Works, Ltd.

Any discussion of the scope and methods of applying scientific research to an industrial concern must take into account at an early stage the important distinction between those industries which have been built up during recent years on the direct application of a particular branch of science and those, mostly older, industries which up to the present have prospered on empiricism. In the present contribution attention is focussed on the former group in which men with scientific training are employed in some form of organisation expressly devised to carry out research.

While industrial research has been practised to a limited extent for many years and, during the past twenty to twenty-five years has assumed an established position in British industry, it can be said that there is still much of a tentative nature in the arrangements for carrying it out. There is by no means unanimity of opinion on the details, and different firms are at the present time conducting research as a separate activity with little or nothing in common in their administrative methods or organisation.

The end of the 1914-18 war saw a sudden spurt in the adoption of scientific research in industry and it would be a valuable landmark at the present juncture, when another world war has again given prominence to the subject, if we could consolidate the position by establishing certain desirable principles which have now evolved in the general organisation of such work. Naturally a word of warning should be uttered lest an attempt be made to crystallize the position too early and to stereotype matters which should still remain fluid. While giving full consideration to this point of view, however, we may agree that the time has arrived to ventilate the subject and, in dis-

cussion, to examine the possibilities of developing certain basic ideas as a guide to those concerns already conducting research as well as to newcomers in the field.

Before details of procedure are discussed the objects of establishing a research unit must be reviewed. In the first place, in the type of industry under discussion, the main broad purpose of the research organisation must be to keep abreast of scientific knowledge which is ever increasing and to ensure its application in the firm's day by day activities. In many concerns it seems to be assumed that knowledge is static and that having engaged an expert all that is necessary is to secure his close co-operation hoping that he will prove to be a perennial source of information. The maintenance of the closest possible liaison with outside sources such as research associations and institutes, D.S.I.R., current literature, personal contacts, meetings, universities and other places of learning should be a prime function of the research department.

The application of this knowledge in the firm's interest will come through the subsidiary functions of securing the highest possible quality in the product consistent with economic considerations, the improvement of processes of manufacture and introduction of new ones, the use of new raw materials, and the development of entirely new products.

These various functions can, of course, be broken down a stage further, as for instance the carrying out of research on materials, processes and products, the drafting of specifications for raw materials and finished products, and the development of new testing techniques. The maintenance of the closest possible co-operation with the production staff ensures the prompt application of the knowledge established by the research staff. Co-operation with the sales staff results in a mutual appreciation of scientific and technical trends in the markets for the firm's products, often requiring new products or modification of existing ones.

For several reasons it is essential in a manufacturing concern to assemble the research group in a separate department, clearly defined but tied in with all other departments at many points. To admit that the staff most suited for research requires working conditions of a kind different from those existing in the production department is not to place that staff on a pedestal but to face obvious practical facts. It is important for instance that a research man should be continually dissatisfied with the technical status quo, whereas too close a daily contact with things as they are may blunt the critical faculties on which his value largely depends. Further the general outlook in a research

department admits frequent failure as a regular part of the price paid for an infrequent success ; in production no failure is condoned. In addition research staff may be profitably employed in the firm's interest in a manner which on the production side would appear to be absence from duty or inattention to the work in hand. For all these and many other reasons separate accommodation and to some extent special treatment of research staff, arising from the special character of the work, must be accepted as a condition for maximum usefulness.

The organisation of research in an industrial concern divides itself naturally into the internal organisation of the research department and the broader question of the place of the department in the concern. Taking first the question of internal organisation, we are faced with the problem of providing arrangements which will on the one hand establish some kind of order in the administration with co-operation between units, and on the other ensure the flexibility so essential to encourage work of an individual and often inspirational nature and to provide for all those unpredictable combinations which experience shows do develop in the carrying out of research. The application of research, while it must be planned to a limited extent, cannot be planned entirely on rigid routine lines, until it results in a product or operation that can be standardised.

The best solution to this rather difficult problem seems to be to construct a rigid framework to carry all those functions, the nature of which can be predicted with some certainty on existing knowledge, and to superimpose a second structure with more freedom from restraint. As an example of the second component there are to-day in several of the large research organisations in this country and abroad highly qualified senior scientists not charged with any administrative or specific duties of any kind but with complete freedom to apply their ability and experience in the manner of a free lance. They are encouraged to investigate at the fundamental end of the research scale, to publish contributions to the learned societies which have a considerable prestige value to the laboratory to which they are attached, and to advise and stimulate the younger members of the staff. They are always available to the director of the laboratory for special advice and help.

Before considering other desirable freedoms in the internal application of research it will be advisable to pay some attention to the rigid framework of the organisation. In the first place there must be an administrative head with some such title as Research Manager, Head of Research Laboratory, or Director of Research. Although the latter title is usually frowned on, unless the individual is a member of

the Board of the Company, (which is eminently desirable, since all questions of policy must both affect and be affected by technical considerations), it is a convenient one to employ in this discussion.

The selection of a Research Director is the first step to success or failure in any application of research to industry. Here we are faced with a very real problem as there are so few workers in the research field who seem to be able to appreciate all the many possibilities for growth which are latent in a research team. In a research organisation, before all other types of industrial units, the choice of a leader is of prime importance and the responsibilities of that leader when chosen are correspondingly great. It is not sufficient that he should be a first-class scientist, and yet he must possess a reputation for his scientific qualifications and achievements in order to carry with him his own staff and to secure the acceptance within the concern as a whole of the recommendations which he issues from the research department. The complete specification of the ideal Research Director would carry a long list of characteristics, but above all he should possess energy and inspiration and the ability to engender the same qualities in others. A reasonably modest outlook in dealing with the industrialist of long experience with whom he comes into frequent contact during the course of his work, and a willingness to employ on his staff experts who know far more than he does in particular branches of the different sciences employed, also constitute valuable qualifications.

Presuming the right type of Research Director has been installed, he can subdivide the work on one of various schemes depending largely on the nature of the associated business. Classification may be attempted according either to the particular works product or to the branch of science involved. For instance, in an engineering concern there could be say, gas producers, pumps and presses, and boiler sections or alternatively chemical, mechanical and metallurgical sections. In a research laboratory serving an electrical firm, there could similarly be sections for lamps, electronic valves and radio on the one hand or on the other physics, glass technology and electrical sections.

If, however, one lesson has been learned by those engaged in the organisation of industrial research during the last quarter of a century, it is that such attempts at producing a genealogical tree with separate units in watertight compartments is entirely impracticable. Whether classification be by products or by branches of science there must be constant overlapping. This is not admitting, however, that chaos is inevitable in research administration: there is a third method. In this method, which might be known as the *nucleate system* of

organising research in an industrial concern the general idea is that sections are not arranged in parallel, each under the Director, but grow one from another. In the innermost depth of the organism is a research nucleus which is the focal point of all activities in the laboratory. In this nuclear group is initiated research on materials and phenomena associated with all the products of the organisation no matter what science is involved. The leader of this group would be chosen according to the nature of the product and would often be a physicist or a chemist or in specialised laboratories a biologist or a metallurgist. The group would be screened from undue interruption by production problems and would perform the functions of liaison with external academic and industrial groups to secure the fulfilment of the main purpose of an industrial research department defined earlier i.e. keeping abreast of scientific knowledge,

A constant flow of workers between this nucleus and the Universities and research associations would be expected. Being largely concerned with work of a fundamental and general nature this group would be encouraged to collaborate widely and to publish the results of its investigations. The mentality which regards the results obtained in fundamental research as the private and exclusive property of the particular organisation in which they are obtained does, of course, still exist, but it is now clearly established that research of this kind carried out under such restraint is doomed to failure, and freedom of publication should be a *sine qua non* at this stage. There will always be the occasional genius who can sit and think research without any contact with his fellow-workers, but men of this type are so few in number that we can disregard them entirely when we are considering the general organisation of industrial research units. Freedom to co-operate with scientists outside the organisation is the life blood of the research nucleus.

A further feature of this nucleate conception in which we have research within research, is its possible reaction on the time-worn discussion as to whether " pure " research should be the function of the Universities or of the industrial unit. Conceived as outlined the research nucleus forms a merging point between industry and the University, so that the problem largely disappears.

Having defined this nucleus the next question to settle is the securing of the practical contacts with the production departments. This field naturally falls into two groups of activity : (1) Process and (2) Development—the former to secure the maintenance and enhancement of quality of product through control of raw material and process and the latter to develop new and improved products.

The Process Group will lay down detailed specifications for the production processes and will collaborate with the production staff in every way possible by carrying out control tests. They will deal with day-to-day difficulties as they arise, referring to the Research Nucleus matters of fundamental nature. This will usually involve the Research Department in maintaining a staff in the production plant, though these men will not in any way be responsible for normal routine tests on the finished product. The Process Group will only be called on to issue reports when they find cause to recommend a modification of either material or process standards or require a fundamental investigation carried out by the Research Nucleus.

The operations of the Development Group will arise in many different ways. In order to meet competition or to enter a new field of business the Commercial Departments may require a modified or entirely new product, and requests may come from a customer for some new device to meet a special requirement. The research nucleus may pass on proposals for a new product arising from their fundamental work or the production department may require modification of the product to facilitate manufacture. Advance in technique may also involve the Development Group in the development of new methods of test. A very good example of this is to be found in the revolutionary testing circuits and apparatus which have had to be developed by the electrical industry to meet the rapid increase in frequency at which dielectrics are now employed in radio work.

The importance of the development of new products by a research organisation cannot be given too much attention. It is known only too well how difficult it is to introduce new lines into an established business ; from all quarters come objections to such a disturbance of smooth running. Here the Research Department can provide a small manufacturing unit in itself capable of developing, making, and even selling its own products up to the small batch production stage. This would be one of the functions of the Development Group. If this is done well, there is no difficulty whatever in persuading the factory to take on new lines. On the contrary, there is usually an outcry that it is being unfairly treated in not being allowed to take over the new lines. In short, obstinate opposition changes to covetousness.

It will be at once apparent that the three groups envisaged, while they have much in common, require three different types of staff with three different types of outlook—imagination and ingenuity in the development group, assiduity and observation in the process group, and in the research nucleus a sound knowledge of scientific principles and training in scientific method. Segregation of the groups

on the lines suggested does not by any means involve separation physically. There should be continual cross-discussion at all levels between the groups.

Staffing of research units is another very important matter which has so far received scant and inadequate attention. It has been assumed by most managers of Research Departments that it is sufficient to obtain a man with a high academic degree and give him some specific problem. This is a hopelessly narrow view. Unless a man appreciates all the phases of a Research Department's functions he must necessarily be unable fully to contribute to the work of the team In the early stages, therefore, it is essential that a new entrant should be given as complete a picture as possible both of the work of the organisation as a whole, and the research unit of which he is to become a member. Research trainee schemes can contribute a very great deal to the development of healthy research departments in industry.

In addition to the three main functional groups already defined, certain service groups are a necessary part of the research organisation. There must obviously be an administrative group to handle stores, accounts, personnel records and to provide such facilities as typing, assembly of reports, filing, etc. No modern industrial research establishment can function satisfactorily without its own well-staffed and well-equipped workshops for producing at short notice the experimental equipment required by different groups, for maintaining the various buildings, services and plant, and for producing on a small scale the items arising from the operation of the Development Group up to the stage when they are taken over by the factory.

In any but the smallest research laboratory a photographic section is invaluable. This can operate for the whole concern with obvious advantages in economy. A comprehensive technical record of the company's products and methods of production in the form of prints, lantern slides and films for reference and publicity purposes may easily be a function of the Research Department.

It will be appreciated that, by the adoption of the set-up outlined, the one large chemical, or other specialised laboratory in a research department disappears, and instead smaller ones are distributed among the groups. Moreover the small teams constituting the groups would move from laboratory to laboratory as occasion requires.

Every research laboratory must have a library which can profitably become the centre of technical information for the whole organisation. The extent to which such a library is stocked with technical and scientific books and journals and patent specifications depends largely on the proximity of outside libraries, but in most places it certainly

pays to be generous in this part of the equipment. Many an idea is lost by not being followed up because the distance to the point of reference is too great or involves too much discomfort. Good indexes are essential, and the best index of all is the multi-dimensional brain of an enthusiastic librarian, who should be encouraged to maintain outside contacts ; the best library can only answer a fraction of the queries posed by a live research staff. Abstracting of specialised technical and scientific literature and the circulation of resumés within the organisation are further activities which can fill a valuable role.

Before concluding, a word might be said on the subject of running the paper side of a Research Department. The " case " system is fairly general, in which each investigation decided on is given a case number and title. By collaboration among the investigators comprising the team concerned, and with possible supervision by the Director of Research a programme is first compiled setting out the object of the investigation and indicating the lines along which it is intended to proceed. This can only be a tentative guide to ensure that no ideas are inadvertently lost and frequent revisions and new programmes are usually required as the work proceeds. On completion of the work the investigation is reported on and copies issued to all departments of the organisation concerned for necessary action in the modification of a process or product. Where an investigation is long drawn out, it is usually desirable to file periodical interim reports which have the dual advantage of advising those interested of the progress made and of ensuring that the investigator—always human—takes stock. Further, when an investigation drags on for a long time it is frequently desirable to close it down entirely and open one or more cases with new plans framed in the light of the knowledge gained to date.

In conclusion it is obvious that no one individual can lay down principles for applying research in industry which will be of universal application. In what I have said there must be much which has a restricted application and each must consider his own particular field. Possibly the most important point brought out is the need for an internal organisation based on a research nucleus in which various units in an organisation control one another rather than require detailed individual control in parallel from the director of the department. This scheme, moreover, makes provision for the ragged edge which always exists between new and applied knowledge. As a plea for organisation with reasonable degrees of freedom the paper cannot claim to be more than a basis for discussion.

SESSION IV

The Application of Research in Industry

PAPER II

THE FIRM WITHOUT A RESEARCH DEPARTMENT

By SIR E. RAYMOND STREAT, C.B.E.,

Chairman of the Cotton Board

My favourite story about research comes from America. At a well-known company, under the urgent pressure of war and with the bottomless purse of the State, a dazzling succession of new products had been devised. On the wall behind the chair of the brilliant man who was director in charge of research was a notice " You don't have to be crazy to work here, but it certainly helps."

There is a germ of truth in that joke. The pace and scope of scientific development in relation to industrial processes and products are going to be so remarkable in the next decade as to surpass ordinary imagination. To grasp the implications of these far-reaching possibilities a touch of the combined vision and energy which that director, with genial irony, called craziness, will not be out of place.

It is not only, or even mainly, a matter of completely new products like nylon or penicillin, though there may be plenty of these. For many industries profits and prosperity may depend on the application, in combination, of a number of quite small, quite undramatic, outcrops of the scientific activities of an era of research. For example, new methods of measurement may yield information about an existing process or product which permits a new approach to economy or efficiency capable of representing four or five, or ten or twelve per cent. in the profit and loss account.

The fact is that scientists, after digging away in the deep mine-shafts of fundamental knowledge for the first forty-five years of the present century, have now begun to come to the surface of the ordinary world of affairs, laden with their finds; and, apart from new discoveries, we could well spend the next fifty-five years of this amazing century digesting and applying what is actually or potentially available at this moment.

If I were the owner or managing director of an industrial firm with a turnover too small to permit me to afford a research department and a scientific staff, this situation would give me furiously to think. What was going to happen to me, I should wonder, in this coming era of hectic application of the fruits of scientific research ? Were the big firms in my industry going to leave me miles behind ? Would my wealthy competitors in America sweep the board ? Would the State resources of Russia be so deployed in this connection as to bring about advances there which would alter the whole balance of international trade ?

The problem of what the relatively small firm can do and should do in these circumstances is a matter of critical importance. It is possible to imagine that in the absence of an adequate solution we might be faced as a nation with no other alternatives but compulsory amalgamation of small units into larger ones or nationalisation of all industry. I happen to be amongst those who believe that as regards qualities of initiative and flexibility the small-scale enterprise has something which from a commercial angle, particularly in certain industries, is a national asset which would be lost to the nation if all industries were compulsorily amalgamated or nationalised. I also believe that the small concern has a moral and psychological significance in the life and outlook of our society and that we should be a great deal poorer, in human values, if everybody of necessity had to be a servant of a vast corporation or the State itself.

It is by no means easy to draw a line between the small firm and the large, between the firm that can have and should have a separate department for research and development manned by scientifically trained personnel and the firm which obviously cannot afford such a department. If you take a shot at a venture and fix the boundary line at 1,000 employees, you find that in 1935, when a Census of Production was taken, only 1 per cent. of the firms engaged in factory trades come above the line. This 1 per cent. of firms (about 600 of them) employed 21 per cent. of the total workers and were responsible for 24 per cent. of the output. You may think the boundary between large and small firms should be fixed much lower than 1,000 workers. Another 3.5 per cent. of firms were those employing between 400 and 999 workers. In total they employed 19 per cent. of the workers and were responsible for 19 per cent. of the output.

The figures for all factory trades cover wide differences as between separate industries. In electrical engineering large firms account for 60 per cent. of total output : in cotton weaving only 10 per cent. of the output is from the large firms. These figures only confirm what

we should expect from our general knowledge. The highly technical and highly scientific industry develops large units because of the heavy capital costs and the indispensability of expensive scientific and technical departments. The industries which have grown out of ancient craftsmanship present a picture of small concerns and family ownership. The figures show how much of the nation's well-being is at stake in the resources and policies of the small firms.

In short, we face a period of intensive scientific development, with approximately half our industrial output and half our industrial employment depending on the success and prosperity of small firms. Yet small firms obviously cannot afford to employ research personnel of sufficient attainments or in sufficient numbers to cope elaborately with conditions arising during times of active scientific development.

In the light of these facts we must attempt to formulate the principles and outstanding features of a policy regarding research suitable for small firms. To hope to do so with any real helpfulness it is necessary first to identify and classify some of the factors in the situation with which we aim to cope.

Research is potentially capable of yielding results which may fall under one of five heads. These are :—

(a) new products
(b) use of new products evolved by others in improving upon or economising in the production of the same article
(c) refinements in machinery
(d) refinements in processes
(e) better methods of control, leading to improvements or economies.

Generally speaking, new products, that is genuinely new products not merely variations on old themes, tend to come from big firms and big expenditures on research. Exceptions arise to this rule, as to every other. For example, in fine chemicals a small firm may evolve a new product, but for small firms in most industries the question of searching for new products may be disregarded in policy making. On the other hand, the prompt use of new products evolved by others is particularly a province for the small firm with the assets it possesses of flexibility and intimacy of its managerial set-up. Minor refinements in machinery are attractive possibilities for small firms : major developments in the machinery field, on the other hand, are more likely to be undertaken by firms with large resources. Similarly, with refinements in processing and as regards better methods of control, everything depends on the way in which the business is run, whether largely by traditional practices or with elaborate recording. As a rule

there is no barrier on grounds of expense to a reasonable elaboration of recording in a small business—it is a matter of the outlook of the management.

We all know firms in regard to which we would willingly place a bet that nothing resulting from scientific research will occur in their undertaking unless it has already occurred elsewhere and they hear of it and copy it. The management may have other virtues but the knack of origination is not one of the characteristics possessed by them. Yet in an era of research this quality is of supreme importance. It is worth-while to reflect, therefore, what this knack of origination consists of. I suggest that the first part of the answer is to be found in the word "Recognition."* You have to recognise something wrong before you busy yourself to put it right. You have to recognise a possibility of improvement before you are in the slightest degree discontented with what exists. Any particular man's aptitude for origination may be slight in any case but he will certainly not exploit it as fully as he possesses it if he does not develop this function of "Recognition." In any attempt to be research-minded it therefore seems essential to start with "recognition." It is proverbially difficult to look for a needle in a haystack. Looking for advantages from science may be as difficult for the small firm unless, as a first step, there is a deliberate "recognition", of certain objectives which are in view. This act of recognition may be either the identifying of a problem arising internally within the factory which merits scientific investigation or contacting some item of knowledge available externally and realising that it may have some possibilities internally.

The kind of firms we are mainly considering will necessarily have a limited number of persons in anything resembling a managerial capacity. There will be an owner or managing director and anything from one or two up to half-a-dozen men engaged in supervising production, sales and administration. At the present time it will be only by a rare coincidence that any one of these men will have had a scientific training. They may have studied a limited field of technology which, however desirable and helpful, is not the same thing as a training with a true scientific basis. In America many thousands of university graduates from the schools of natural science and technology are found in industry. In Germany before the war, in Switzerland and Sweden now, and probably in Holland, the same position holds. The situation cannot be remedied for some years to come, but in due course I hope smaller firms will draw many more of their prospective

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* *I am indebted to some notes written by Mr. C. G. Renold (Chairman of the Renold and Coventry Chain Company Limited) for the conception, "Recognition - Investigation - Application."*

managers from graduates whose training will have been of the most adequate kind from the standpoint of the scientist. Sons of owners destined for the family firm should take science degrees almost as a matter of course. Meanwhile we must deal with things as they are and this function of recognition must be deliberately cultivated notwithstanding the lack of undoubted advantages which even a rudimentary grasp of the principles of the scientific method would carry. It will only be born by practice out of determination. It will only flourish and grow where there is perseverance and faith—and above all, keen interest.

Following recognition comes investigation. This is neither more nor less than an indefatigable search for every possible item of fact or knowledge bearing on the point at issue. Such a search must be internal as well as external. Internally the aim must be to observe and measure and record everything connected with the problem so that when knowledge is obtained from outside it can be applied to what is inside. Externally the search must be in scientific institutions and amongst suppliers of materials or machinery. If the industry possesses a co-operative Research Association that is obviously the place to begin. The possibilities of help from suppliers of materials or machinery should never be overlooked. The small firm may buy his chemicals, for example, from a big firm. That big firm may be most interested in a problem " recognised " by a small firm, the more so if the big firm could never have " recognised " it itself for the simple reason that it does not operate in the particular field.

Finally comes application, which will consist of introducing the changes of practice or design suggested by the investigation. Here again the intimacy of the management in small firms may well prove an asset.

Recapitulating what I have been trying to establish, I would say that the principal functions in a policy of research-mindedness can be classified under three headings, namely :

(a) Recognition.
(b) Investigation.
(c) Application.

In a large firm which maintains a Research Department there is one man at the head whose whole time and energies are occupied with the matters I have just been discussing. The problem for the small firm arises from the fact that all its responsible personnel have other things to think about and to do which by their nature clamour more obviously for attention than research will do. It is therefore necessary

that most deliberate arrangements should be made to ensure that research should get its due share of attention. No matter how small the firm or how lacking in scientific training its personnel one person should be nominated to hold himself responsible in the matter of research. The three key words, Recognition, Investigation and Application should govern his activities. As a foundation, he should receive, index and file information regarding research. He should be placed under an obligation to make a documentary record at stated intervals of happenings on the research front and to submit it to his superiors or colleagues for comment and discussion. A set time and place for formal discussion is important. In a small firm, things may be casual. The casual method is the antithesis of the scientific method.

Many possibilities will reveal themselves to the "research man" in pursuing his aims. He can visit a Research Institution. He can organise a visit to the factory by a member of the staff of a Research Institution. There are many scientists engaged in teaching or research who can be brought to a factory or works if enough ingenuity or perseverance is displayed. It is not out of the question to find an academic scientist who for a retainer within the resources of the smallest firm will be interested to act as scientific consultant, familiarising himself with the works and discussing new and old knowledge with the management at stated intervals. There are consultants who can be brought in to see what they can do, first in the way of "Recognition" and afterwards, if agreed, in application. In Manchester, the University and the Chamber of Commerce have jointly established a Research Council with a whole-time Liaison Officer who will be glad to direct the "research man" of any small firm in the North-West to places and people where and from whom information and ideas may be forthcoming. The Federation of British Industries Industrial Research Secretariat will help similarly all members of the Federation, and as time goes on I hope other organisations will provide a research service for the smaller firms. It is possible, also, for a small firm to arrange with some university or institution for a particular enquiry to be pursued by a particular scientific research worker under a grant provided by the firm.

These activities, whichever form they take, will cost money as well as the time of the "research man" and other members of the management. Small firms sometimes have small ideas as to expenditures of certain types. Rents, rates, fuel and lighting are unavoidable expenditures but they fight shy of what they are apt to regard as "non-productive" expenditures. It will be necessary to take a different view of expenses incurred on research activities. They must be regarded as potentially very productive indeed. It would be con-

sidered foolish to make the operatives work without enough light to see what they are doing. It is just as foolish to expect management to succeed without the light which the most up-to-date scientific knowledge can shed. All subscriptions to recognised Research Associations are admitted by the Inland Revenue as chargeable in full as business expenses. So likewise, under recent legislation, would be fees payable to scientific consultants or the cost of other activities I have proposed. I suggest that small firms should fix a percentage of profits which it will be their set policy to expend on research. If every firm with over 100 employees so fixed say on 5%, and charged one member of their managerial team with the duty of recommending expenditures up to that total, "research-mindedness" in this country would register a great forward leap in the next five years

I would like to emphasise the special importance of adopting a settled plan of action. Many small firms are very personal in their set-up and way of carrying on. Everything revolves round the owner or managing director. He often directs matters without relying on set rules or routine. Science, on the other hand, demands discipline and order from those to whom she may eventually reveal her secrets, her wealth or her power. Team-work is more likely to succeed in scientific fields than solo-work. The cross-fertilisation of minds and energies is often the key to success. Owners and managing directors of small firms should not work alone on research questions, and the advantages should be recognised of a formalised plan of action and a disciplined fulfilment of it.

I said earlier that if I were at the head of a small firm in this era of research I should be given furiously to think. Allow me to summarise where my thinking would lead me, at any rate as to first steps. These would be :—

- (a) Decision as to expenditure on research activities.
- (b) Appointment of the firm's "research man."
- (c) Decision to hold regular formal conference on research matters.
- (d) Adoption of the five heads for research enquiries, each to be subjects of report at the regular conferences.
- (e) Adoption of formula "Recognition—Investigation—Application" as guide for "research man."

That would be a good beginning : the outcome would depend on the patience and vision with which the course so planned was followed up.

Before closing I wish to refer to two incidental matters which in my opinion deserve consideration in connection with the application

of research. The first is protection of the fruits of research. A new product or an improved method is obviously of greater value to the degree to which it is the preserve of a single firm. Hence, of course, the large sums which big firms spend on patents and brand names. Very often a new product or an improved method calls for heavy expenditure in development and only a firm with substantial resources can afford this expenditure. If an item of knowledge is located at a co-operative Research Institution it should be and presumably will be available to all members, large and small. The large firm will not spend considerable sums developing the application of such new knowledge unless by patent or branding it can confine the advantages to itself long enough to recoup its development expenditure. Likewise the small firm, even if it had large enough financial resources. So such knowledge and ideas originating in such quarters may never be efficiently developed. Worse, they may be half developed or degraded or debased by firms who do not really care because any competitive advantage for such firms individually is so questionable with every rival at liberty to do the same.

I believe there are devices and procedures available by which Research Associations could obtain for all their members, large and small, and by which groups of small firms could obtain for themselves that protection against infringement and debasement which is essential if the application and development of an item of scientific knowledge or research is to be commercially attractive. I suggest to the organisers of this Conference that this point merits investigation in a research spirit, and if my suggestion is taken up I will gladly make suggestions in detail which I cannot develop in this address without prolonging it unduly.

The second of my two incidental points is the question of secrecy. I think in many circles in British industry the habit of secrecy, which is not wholly unreasonable on competitive and commercial grounds, is carried to absurd lengths. Far better welcome visitors to your works, even your rivals and competitors, than stagnate. The man who really believes himself to possess fully as much competence and courage as the next man should welcome exchange of visits, exchange of information, collection of production statistics, and so forth. He will get more than he will give. From a research point of view, he may get just the missing idea.

It is not without interest in this connection to mention "Operational Research" as developed during the war. The full story has yet to be told, but in public speeches by some of our leading men enough hints have now been dropped to make clear that, under

the title " Operational Research," an approach was developed which yielded rich dividends. I believe it amounted to this : that on the spot, where operations were proceeding, teams of scientists found out facts about those operations which made it possible to increase our offensiveness or defensive effectiveness by remarkable percentages. The results were wonderful, but, if I may say so without detracting from the work done, the actual thing was not wonderful—it was merely logical. The scientific method was employed. Everything was measured and recorded, nothing taken for granted. No traditions or ingrained habits cramped the style of the scientists. They saw possibilities of improvement which had eluded the vision of the practical man. This was no reflection on the practical man—the war effort needed him and his kind every bit as much as the scientist. We must bring to bear on small firm industry some of these principles which lay at the back of " Operational Research " during the war.

My last word shall be this : that whilst there are obvious limitations surrounding the small firm in matters of research, there are also advantages peculiar to small firms, and having regard to the era of scientific development which lies ahead of us there should be no firm in the country which has not a plan in writing, however modest, for activities in matters connected with research.

A man at the head of a business who was not himself at all scientific was showing to a friendly rival his budget for research activities. The friend whistled and said he had no idea the sum would be so large. He asked if the expenditure had proved a paying proposition. The first man said, " Yes, we are sure it has been so, but even if my accountants proved otherwise in any year I should go on. We are entitled to get some kick out of our business lives and research is what gives me the best kick of all."

May there be an ever-growing number like him. If so, British industry will hold its own in days to come.

SESSION IV

The Application of Research in Industry

DISCUSSION

"Liaison"

SIR ROBERT PICKARD, F.R.S. (formerly Director of the British Cotton Research Association), pointed out that the importance of establishing a good liaison between the research workers and the production side, which had been stressed at previous sessions, was further emphasised in both papers of the present session as well as in the Chairman's address. The primary difficulty was that the scientist was rarely adept in expressing his ideas in the language used in the works, hence the importance to firms of all sizes to appoint someone capable of appreciating what is going on in the two fields—production and research.

He referred to the liaison department which had been set up many years ago at the Cotton Research Association (Shirley Institute). The head of this department was a man who had previously been a works manager who had attended the Manchester College of Technology evening classes. The department was staffed with many of a similar type who were given standing instructions to visit the laboratory one day a week, and member firms of the Association during the remaining days. They would discuss with managers and foremen the recent reports of the Research Association, and ask for comments; whether any difficulties had been experienced with them, whether the works people thought they could easily be applied, the extent to which they would be useful, and whether they appeared likely to lead anywhere.

He pleaded with the scientists to cultivate a mental humility, cocksureness about the solution of a production problem was unwise where it was generally difficult to be certain of all the factors, and he ventured to suggest that a certain want of such humility was not unknown among the executives of some firms.

The suggestion by Sir Raymond Streat that small firms should and can obtain scientific advice from the staffs of the Universities or Technical Colleges was a very practicable one, and he called the attention of the Conference to a suggested 'Code of Practice' (drawn

up by the professional Institutes of Physics and Chemistry) dealing with the consultation of private firms with academic scientists.

He stressed the importance of the research worker in industry becoming fully aware both of the ultimate consumer's needs and also of the economic policy of his employer.

He welcomed the importance (mentioned by the Chairman) of the Universities training more science graduates of a general type as distinct from specialists, and thought that with the increased funds voted by Parliament at the instance of the Chairman and the present Chancellor of the Exchequer, the Universities could be expected to meet that need.

"Application" and the "Group"

DR. J. G. KING (Director of the Gas Research Board) said that while agreeing thoroughly with the two papers which had been presented he wished to add a few further thoughts. He felt that the primary problem to-day was that of applying the work of the research group to the continued progress of industry. The organising of a research group was now clearly understood by senior industrial scientists.

Regarding Dr. Dunsheath's concept that the focal point of the research department's activities was a relatively untrammelled academic centre, while he agreed that no research department could long survive without a fundamental group having extensive liaisons with pure science, he felt that the function of this group should constitute it a focus of *attention* in the research department rather than a focus of *activity*.

Sir Raymond Streat's prescription for industrial health, namely the introduction of more technical men in administrative posts had been taking place for several years, but required to be extended, especially as many scientists appointed to research departments subsequently found that they could do more valuable work in executive or administrative positions.

So far as Research Associations were concerned they might become a 'nucleus group' for the whole industry. On the other hand they could work on co-operative lines with similar groups belonging to the larger firms. Following this up collaboration between industrial groups might enable them to organise one 'development group' which could refer back to the research association on basic problems.

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*Joint Council of Professional Scientists, London, November, 1945.

This would enable smaller firms to participate in trials of semi-scale models or new prototype plant. He had personal experience in controlling from a research centre technical research work carried out by small firms which had stimulated the latter's interest in work of this kind and made them wish to extend it. Publication of results of such firms' work would still further encourage their enthusiasm.

"Civil Engineering Research"

MR. H. J. B. HARDING (of John Mowlem & Co. Ltd.) referred to the small amount of civil engineering research until recent years, although the materials for construction were covered by manufacturing industries. There was however much to be done in finding out more about the nature of sub-soil deposits and the laws governing their behaviour. In civil engineering construction the contractor started from scratch and no two jobs were similar. A thorough site investigation was of vital importance, especially before a new factory was constructed, but far too often this was limited on so-called economy grounds.

It was only recently that contractors had recognised the advantage of employing scientifically trained engineers who were aware of the valuable work carried out by the Building Research station and the Roads Research laboratory. The Geological Survey in this country required to be encouraged and to be given more facilities for carrying out its work and co-ordinating information and for keeping itself up to date.

"Research into 'Seating'"

MR. M. A. H. CHRISTIE (of Christie-Tyler Ltd.) said that the problem of the correct way of supporting the human frame in industry was generally overlooked, although it was very relevant to the present appeals for greater production output and better working conditions.

'Seating' was something to keep the body so many inches from the floor to enable a person to carry out an operation. It could make or mar the efficiency of the operator.

This problem had been especially important during the war in long-range coastal aircraft, and had been solved by the Air Ministry experts and the medical profession together. It was important in peace time, for example car driving, typists, or the audience of a theatre or concert hall. Greater comfort at work was the direct way to greater

output. There was need for co-operative research by the seat-makers' Medical Research Council and Industrial Research Associations to decide what types of seats were required for various industries, purposes, etc., and for publication of the information obtained.

"The Place of the Technical College"

Dr. T. J. Drakeley (Principal of the Northern Polytechnic, and President of the Association of Principals of Technical Institutions) said that the countries who were applying knowledge to-day, and who were incidentally our chief competitors for the world's markets, possessed well-recognised schemes of technological education. If Britain wished to attain competitive equality to develop industry and scientific achievements and regain pre-eminence in world markets, higher technological education would have to be developed. At present there were no Technical Colleges in Britain comparable with the world-famed Technical Universities overseas, nor were those that did exist given a status in their higher technological studies similar to that of the Universities. Every effort should therefore be made to support the Percy Committee's view (in its report on 'Higher Technological Education' 1945), that research was a necessary concomitant of all higher teaching, and that facilities for research afforded by the large Technical Colleges should be used to the full.

A satisfactory training in technology must include a sound and adequate education in the basic sciences, so that it was in effect a true scientific training. Technical courses would have to be extended to meet industrial needs so that industry could be supplied with men trained in the application of scientific research. Such strengthening of the Technical Colleges would attract a fair proportion of the best brains of the country to its technological courses from which both industry and research would benefit.

Interdepartmental Co-operation"

Dr. J. L. Stoves (of C. W. Martin & Sons Ltd.) pointed out how essential it was that the link between research and production should be healthy. The research department should be taken into the confidence of management and production, and in the consideration of any problem all relevant information should be given. Lack of full co-operation must inevitably delay fruitful application and it was therefore necessary for research and administrative staff alike to cultivate this spirit by all possible means.

It was also important that industry should now shoulder more adequately the burden of fundamental research. The scope and facilities of the universities needed to be extended, and industry, through research associations and the laboratories of larger firms, could supplement the work of the universities by carrying out their share of the work of fundamental research. It was an important and long-term investment.

"Information Services"

MISS E. M. R. DITMAS (General Secretary of the Association of Special Libraries and Information Bureaux) referred to the important function of the scientific information services. The information officer was really an intellectual liaison officer. No scientist could read all the relevant literature and needed to be kept in touch with the latest publications. The liaison officer assisted him by maintaining wide contacts and in the small firm his function could be combined with that of librarian.

The Association of Special Libraries and Information Bureaux ("Aslib") had been studying these problems for twenty years. The Association's Conferences provided a means whereby information officers could exchange experiences with others working in neighbouring fields. Aslib was grant-aided through the D.S.I.R. and was so constituted that it covered the whole field of science, art, and technology.

"The Independent Consultant"

MR. H. D. MURRAY (of Murray, Mactaggart & Co. Ltd.) referred to the value of the independent consultant in industry in supplementing the activities of the trade research associations and stressed the value of independence when a consultant was required to act in certain matters.

Sir Raymond Streat had suggested that a small firm should appoint a member of the executive to concern himself with research matters. Where no member of the firm had an adequate technical training the appointment of an outside consultant might be preferable.

The further suggestion by Sir Raymond of frequent and regular conferences on research matters was strongly to be endorsed. By such conferences the executives of a firm became research-minded and a research programme could then be carried out in an effective and orderly manner.

The independent consultant found his main usefulness with manufacturing concerns which did not possess a research organisation. His independent standing permitted him to enter into a confidential relationship with the board, similar to that subsisting between solicitor and client, and helped to maintain the highly individual character of the average manufacturing concern in this country. The speaker thought there might be danger in putting too much emphasis on the benefit of co-operative research, lest in doing so the virtues of initiative and independence be lost in a dead level of uniformity.

"The Smaller Firm with the Research Department"

MR. G. A. DUMMETT (of the Aluminium Plant and Vessel Co. Ltd.) said that there were many small firms with research departments. In such cases research was of even greater importance and the problems of its organisation differed from those of the large firm.

First, the number of long-range problems which could be investigated was limited and selection had therefore to be made with greater care. Second, the direction of research needed very close integration with production and sales policy. It should be in the hands of one man familiar with all three activities, or where this was not possible in the hands of a small committee. Third, the fullest use had to be made of collaborative research carried on with university, Government, research association or other industrial laboratories. Fourth, the selection of research staff was of the greatest importance. Staff had to be paid well, offered attractive conditions of employment, be versatile rather than specialists and work together as a team of friends. Fifth, the balance had to be struck between production investigation ("trouble shooting") development work (plant or process) and long-term research. The tendency to squeeze out the last had to be resisted, and a rough guide to the distribution of expenditure might be as 1 : 3 : 2 respectively. Sixth, the laboratories should be well equipped with the best apparatus available (which saved time, men and money). Finally the research people must work in the closest touch with other departments so that the research section can act as a first-class training ground for men to be promoted to technical posts in other departments.

"Present Handicaps"

MR. STANLEY ROBSON (Director of Research and Development, Imperial Smelting Corporation Ltd.) suggested that the Conference should underline the opinion already expressed that scientists working

on fundamental problems, whether in the Universities or independently, should always have in mind the possible industrial applications of their work. While research, for its own sake, was provocative and had led to the greatest of all contributions in the hands of brilliant investigators like Rutherford, Faraday, and others, much of the orderly progress of industrial development depends on more purely objective research.

He believed that this country would gain much if the facilities of a Battelle or Mellon Institute were available. Small manufacturers would be greatly helped by being able to refer their special problems to this type of Institute, which is able to divert teams of competent investigators to their solution, and is willing to give them the sole benefit of their work.

If some munificent benefactor would establish an Institute of this type in this country, it would fill a serious gap in our organization of research.

Finally, the publication of technical literature was seriously handicapped by paper shortage and related difficulties. Attractively presented and illustrated technical papers were an important form of national advertisement and the Government should grant adequate paper and facilities to permit of proper presentation of such matter. Our publications were in this respect at a disadvantage compared with the corresponding American journals.

SUMMARY OF THE CONFERENCE PROCEEDINGS

By SIR WILLIAM LARKE, K.B.E.,

Chairman of the F.B.I. Industrial Research Committee.

This Conference is a sufficient demonstration (if such be needed) of the full realisation by Industry of the responsible part it has to play as the instrument of economic recovery and an improving standard of life. This Conference represents the authentic voice of Science, Industry and the Government, since Ministers and leaders of the nation in various fields of activity have enthusiastically participated and given us the benefit of their counsel and experience. From this we have derived the greatest encouragement and inspiration. If we secure the full mobilisation of our great scientific and industrial resources we may look forward to replacing Austerity by Prosperity and Hope by Achievement in the not too distant future.

All the addresses and papers presented to us have a particular authority, since for the most part they are records of actual experience and the deductions which may be drawn therefrom. The addresses at the opening session were particularly valuable as creating the background for the whole Conference, indicating many of the problems which await solution, and at the same time indicating the manner in which their solution might be approached.

In opening the Conference, the President (Sir Clive Baillieu) emphasised the importance of the association between Industry and Science in promoting economic recovery, in these words :

> " Only those countries which have the brains and resources, the ability and the will to apply the latest results of science vigorously and continuously for the expansion of old industries and the creation of new ones, as well as to the improvement of productive practice and efficiency generally, will hold their own under the stress of post-war international competition. Only in this manner shall we be able to increase the production of wealth without which it will not be possible to maintain, let alone improve, the standard of living in this country."

The President of the Royal Society (Sir Robert Robinson), in a particularly inspiring address, placed the relation of the scientist to

Industry in its right perspective and emphasised from experience the enormous advantage of effective team-work in attacking any particular problem ; pointing out that within the team the individual must be accorded the fullest possible freedom of action. He advised Industry to :

> " Support the Universities, give them their head and keep in touch with them. Really blind research is better left to the Universities under present conditions."

In dealing with the part of industry, I ventured to emphasise the great responsibility of industry as the instrument of economic recovery and placed its dependence on research in a sentence :

> " Research is a speculation in prosperity ; its neglect a confession of complacency the penalty for which in a highly competitive world is progressive decline leading to ultimate bankruptcy."

Sir Edward Appleton, from whom we have long learned to expect a constructive and inspiring commentary, developed still further the necessity of collaboration between Science and Industry, and defined the function of the scientist in relation to the community generally. He said :

> " The public has seen how the great triumvirate—the Services, Industry and Science—have worked together and achieved complete victory."

and added :

> " One of the most important practical discoveries of this century was the discovery of the method of making practical discoveries."

Sir Harold Hartley, speaking from his wide experience of the actual effect of research on the operations of two of our great national activities (one, the Railways ; and the other, a Gas Company) has demonstrated conclusively that the progress made in these two fields of activity is largely due to the continuous application of research to operating problems, with a resulting general increase in efficiency and a raising of the standard of the amenities of life for the community generally. He concluded :

> " Research is the elixir of life in industry, ever renewing its youth and vigour. Where research is intelligently applied, old age is impossible."

Sir Ernest Simon, from a very special standpoint, focussed the problem of the provision of the requisite qualified man-power. He stated :

> " The battle for full recognition of Science is won. The problem now is how to get quick and effective development."

He indicated the method in which the problem could be effectively attacked. We may express the hope that operational research may be applied to such plans as he has described, with a view to achieving a greater output of qualified men from the Universities and Technical Colleges than even he is able to envisage at the present time.

The papers presented in the sessions which followed collectively represent a most instructive record of experience and suggestion for future development.

The Minister of Supply (The Rt. Hon. John Wilmot, M.P.) in his address pointed out the immeasurable contribution which research has made to the victory of the Allies in rendering possible the development and improvement of existing weapons of war and the production of many based entirely on new scientific principles which were not available even at the outbreak of war; and points the moral that by the application of science by industry we can help to make the life of the ordinary man richer and fuller. He emphasises the fact that in scientific discovery we have made a contribution to knowledge unsurpassed by any other country. He went on:

> "Encourage scientific research and development by all the means in your power; encourage your own scientific workers and your own technicians to study the results of other people's research work; make use of that research work in your own factories; have the courage to scrap obsolete methods and machinery."

Dr. Hosking, in dealing with "Research and Quality", said:

> "The quality factor becomes in general more significant . . . . as competition for markets increases."

He indicated the wide field which must be covered, since it is not only improvements in the process and stages of manufacture which result in the product of a given industry which require examination; but the whole field of the raw materials of that industry, as they often offer even greater opportunities for the improvement of the ultimate product. Thus each industry, in its interdependence on others, must establish close scientific and technological relations with those with which it is related either as suppliers of raw materials or at the other end as users of the product concerned.

In dealing with Research and Production Costs, Mr. Healey says:

> "What we as a country are concerned with to-day is not so much whether we have as much knowledge as other countries (although we excel in the field of knowledge), but whether we are making the fullest use of that knowledge in our industries."

and invites attention to the substantial savings which may be achieved in the economic use of material and the reduction of "wasters" by effective instrumental control of the process; providing an automatic inspection through all stages of production. This should be a common activity of all industries and to the extent that it is successful should exercise a direct influence on the competitive power of industry in world markets.

Sir Clifford Paterson, in his paper on the "Conversion of the Results of Research into Production", has given us the benefits in detail of the experience of his own laboratory (one of the best equipped in the country, if not in the world) and all will agree that his experience in the development of relations between research and production are invaluable as a guide to those who have not reached either the magnitude, or high state of development, on which his record is based. In discussing the functions of the research worker he says :

> "By removing the empiricism in some process, he obtains a new insight into its essentials and is able to put forward some radical improvement."

He points out that suggestions will inevitably arise from the Research Department, indicating the desirability of a change in production processes which the Production Management may well find inconvenient and hesitate to adopt for that reason ; but Sir Clifford Paterson wisely points out that :

> "It is no use fighting a rearguard action against inconvenient progress.'

If it is a good thing, some organisation in the World will follow it up sooner or later. *THE LESSON FOR BRITISH INDUSTRY IN THIS IS THAT NO-ONE MUST FOLLOW UP SUCH AN OPENING SOONER THAN OURSELVES!*

The Lord President, in his encouraging address at the Third Session, gave full assurance to Industry of the interest and support of His Majesty's Government in developing the application of research ; and also the necessity for taking immediate advantage of any opportunity which new discoveries may present for the improvement of our industrial competitive power. He pointed out that :

> "As far as industrial research is concerned, research not applied is just so much wasted effort. As a nation, we have been accused of being too slow in developing new ideas. Things have never been as black as they were painted, but we cannot risk being slow in the future."

Dr. Slade, in his interesting paper on "How New Industries Arise", has touched on the remarkable sequence of events which resulted in the Industrial Revolution. Previous to the mid-18th century, industries as we now know them were crafts; as he points out, the Industrial Revolution gave us a flying start. It is our business in industry to-day to endeavour to create new industries, not only by the application of research, which makes new materials and products possible, but also by the investigation of human needs. In this respect Dr. Slade points out that :

> "Research produces new ideas, which create new kinds of wants."

thus leading to industrial expansion. He concluded :

> "We have indeed done more than our share of providing ideas, and we have done less than our share of making them into new discoveries."

Mr. Davy, in dealing with the "Modernisation of Processes and Plant", also gives us the experience of a large research organisation and describes the conditions and mental attitude in a research department which experience has shewn to be necessary for its success, pointing out:

> "It is not only their duty to produce results—they have also to 'sell' them."

He draws attention to the limitations which quality of material may impose upon design and the ultimate efficiency of the product. An interesting example of collaboration in research between the makers of boilers, the producers of steel and the users of boilers is the introduction of a steel which has made it possible to use total temperatures ranging up to 1,000°F. and thus to increase the steam cycle efficiency by no less than 35 per cent. in the last twenty years.

Mr. Philpot, in describing the value of co-operative research, is able to do so with particular authority, being the Director of the British Scientific Instrument Research Association, which is in collaboration with almost every research activity in the country; and he concludes by saying:

> "Mountains of difficulty confront industry in the immediate future, but faith in the dynamic power of co-operative research can be a potent agent in their removal."

Sir John Anderson, in a speech full of constructive thought and inspiration such as we have long learned to expect from him, is both encouraging and optimistic. We in industry owe him a great debt for recognising the important influence of research on industrial efficiency, particularly in the offices he has previously held—of Lord President of the Council and as Chancellor of the Exchequer, when he introduced the present system of tax relief, enabling expenditure by Industry on research (including both capital expenditure and grants to outside bodies) to be made out of untaxed income. It is desirable to repeat this because Industry has not yet taken the fullest possible advantage of it. Those of us who have been associated with research will endorse his criticism of the tendency of higher education to produce scientific specialists. He says:

> "Little or no thought seems to have been given to the cultural possibilities of scientific subjects."

Most of us with experience in industry and the public services will endorse his plea for the introduction of men and women with scientific training into the public services, as well as into administrative positions in commerce and industry. I should like to support strongly his plea for a new organisation covering the whole field of science under the

ægis of the Lord President of the Council. Referring to the research bodies at present responsible to the Lord President, he adds :

> "The new organisation, covering as it must the whole field of science, should lie outside these but should use all or any of them as circumstances may require."

Dr. Dunsheath's paper, on "The Firm with a Research Department", analyses from experience the various factors necessary to secure the best results, and lays particular stress on the importance of the selection of personnel possessing not only scientific attainments, but the requisite personal qualities. He concludes his paper with a plea—

> "for organisation with reasonable degrees of freedom. The paper cannot claim to be more than a basis for discussion."

May I add that if it stimulates that discussion in industry it will most worthily have fulfilled its purpose.

Sir Raymond Streat, in his paper on "The Firm without a Research Department", urges the necessity of every firm delegating to a member of their staff to follow up the work of research by others that is particularly applicable to the work of the firm concerned. He says :

> "No matter how small the firm or how lacking in scientific training its personnel, one person should be nominated to hold himself responsible in the matter of research."

and he enters a plea for the serious consideration of any scientific result, however removed it may appear to be from immediate practical application. It is a matter of scientific history that some of the greatest discoveries have been made by scientists in the course of their experiments to explain discrepancies which seemed impossible in the light of existing knowledge and which they might not unreasonably have attributed to some experimental error of their own ; but by their persistence proved that the accepted view was wrong and thus opened up a new horizon to scientific exploration.

Sir Raymond Streat also makes a reference to Operational Research, which Sir Edward Appleton on another occasion has defined as "Doing properly that which was already done after a fashion". It has been more implied than specifically stated that operational research should be applied in connection with management and administration. When it is permissible to publish the results of its application to tactics of the fighting Forces during the war, the success will prove to have been decisive in its results Perhaps it is not too much to express the hope that the experience of war will be applied to the conditions of peace in industry and to the work of public administration in the domestic field ; the influence of which administration is and must be almost paramount in its effect on the development of either the production drive or industrial recovery.